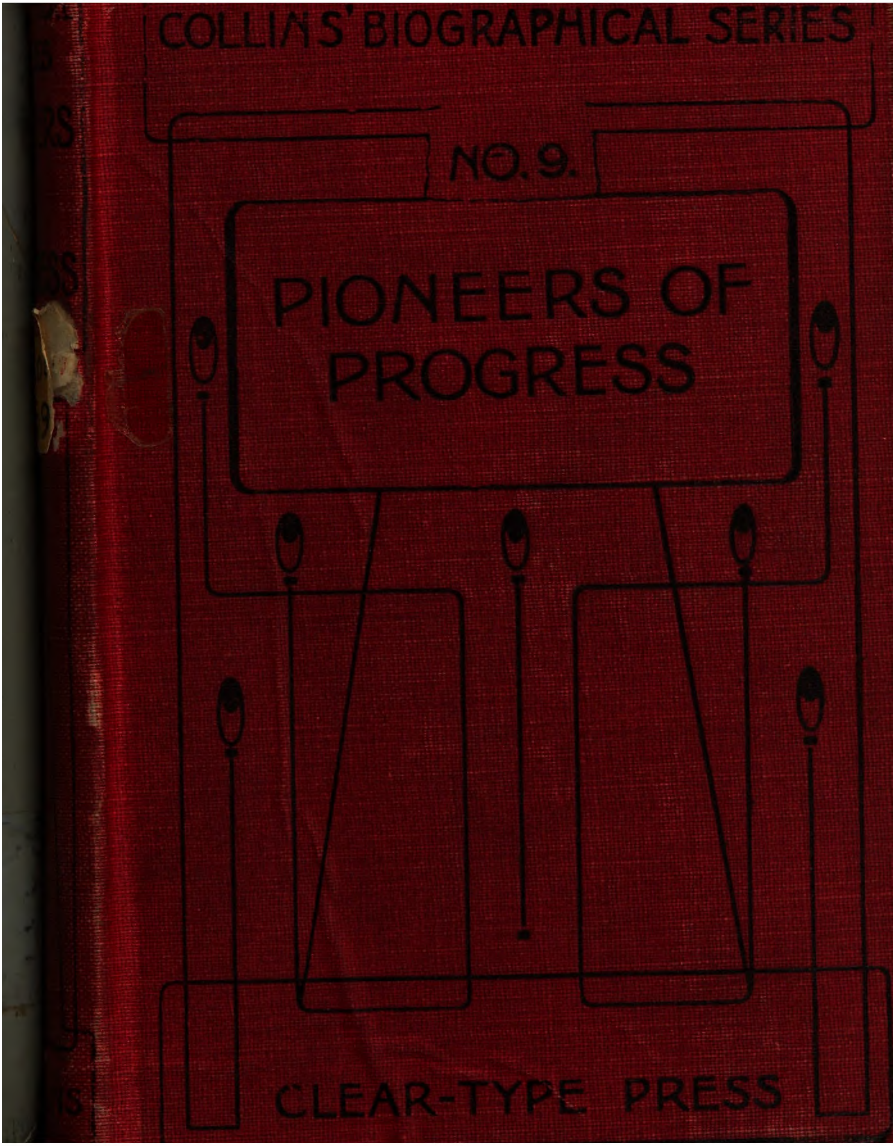

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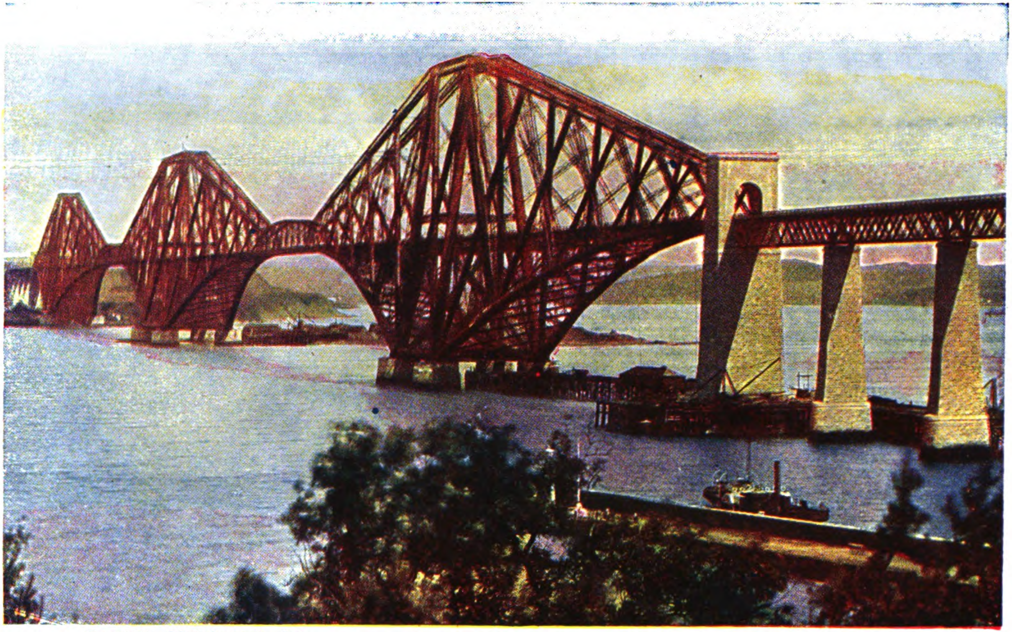

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PREFACE.

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I. Sir Marc Isambard Brunel.

AGES and ages ago, long before men had learnt how to build houses of stone, the scantily-clad races dwelling in the colder lands of Europe and Asia are believed to have taken refuge from the rain and snow of winter, in the caves and rocky passages which pierce so many cliffs and mountains.

Here they carried on their family or tribal life, cooking roughly over their fires of boughs the flesh of the animals killed in hunting, cracking the bones across to extract the rich marrow, and then throwing them carelessly aside. Men of science still find these heaps of broken bones, and sometimes amongst them the bones of some poor cave-dweller who had crawled to his rocky home to die.

These people had, so far as we are aware, little education as we know it, and few tools or implements. Many of them, however, have left, on the smoother surfaces of the cliffs, wonderfully spirited drawings of the animals the pursuit of which filled so large a portion of their lives. Most of the drawings are merely scratched deeply into the rock, possibly by means of the chipped flints which were all they had in the way of chisels and adzes.

With these same stone chisels and adzes, they may be supposed to have cut away with infinite labour jutting angles of rock which marred the comfort of their primitive dwellings, or to have widened the natural passages leading from one cave to another.

There are caves of enormous extent, one chamber opening into another, till the whole great hill seems merely a hollow shell. Exploring these vast caverns by the light of a flaring pine-knot must have been nervous work for these men of ancient days; and we can easily imagine their delight when, perhaps at the end of a long and rugged passage, they saw the faint gleam of distant sunlight, and finally came out into a land unvisited before.

It must have been after some experience of this kind that the idea occurred to these people that, where Nature had not made a way through the hills, man might cut a road for himself. However this may be, we know that in very early times wonderful tunnels were made through hard rocks, from one side of a mountain spur to the other.

It was not always for the sake of a short-cut across the hills that these tunnels were made. Many formed part of the aqueducts or watercourses, by which distant lakes were tapped to supply the needs of towns or villages.

Romans and Persians, Peruvians and Mexicans all undertook works of this kind. Some of the Roman water-tunnels—if we may so name them—were of astonishing length; and, when we remember how simple were the instruments with which the Romans worked, the skill they showed in keeping to the line along which the tunnel was intended to run, is almost more wonderful than the length of the tunnels.

Nearly four hundred years before the birth of Christ a tunnel was driven through the hard lava hills surrounding Lake Albanus, to the south of Rome. This tunnel was more than a mile long, six feet in height, and three feet and a half in width.

The Roman method was to sink a number of shafts from the surface to the level of the proposed tunnel, and then to work both ways from these shafts, till the several cuttings made a continuous passage. In the case of that from Lake Albanus, no fewer than fifty shafts were sunk, and so great was the number of men employed that the work was completed in less than a year.

One of the largest underground aqueducts or water-tunnels undertaken by the Romans was that connecting Lake Fucinus with the River Liris, which was finished A.D. 52. So vast was the amount of work to be done that it is said thirty thousand men were employed for ten years, the cost being enormous.

The aqueducts of the ancient Persians, like those of the Peruvians, were often a series of tunnels connecting well with well, and so conveying a constantly increasing volume of water.

The one point to be noticed particularly about these ancient tunnels is that they were all driven through hard rock, the sides and roof needing little, if any, support. The problem of boring through soft, yielding earth, or through soil saturated with water, was never solved by any of the ancient nations.

During the Middle Ages, after the breaking up of the Roman Empire, no tunnel of any importance seems to have been attempted. Engineering appears to have shared in the general decay of all arts and sciences, except in so far as it was needed in the construction of fortresses and walls of defence.

Perhaps it is only fair to say, however, that the need for very long tunnels of large size was not pressing. Too easy a road from one state to another was by no means always desirable; and the safety of a nation frequently depended very largely upon the barrier of mountain or river or arm of the sea which had to be passed by an invading army. There were underground passages from many castles and cities, it is true; but these were of trifling importance, and needed little constructive skill.

It was not until the eighteenth century that any large tunnel was excavated in Britain. In the latter half of that century, Brindley, the famous canal-maker, found himself compelled to pierce several rocky ridges in constructing his system of water-ways.

Later still, Thomas Telford, the man to whose engineering skill we owe the Caledonian Canal, besides many other important water-ways, drove a tunnel more than half a mile in length, fourteen feet wide, and sixteen feet in height, to enable the Trent and Mersey Canal to pass the hills at Harecastle.

At that time there were, of course, no railways; and the only ways in which goods could be taken from one part of the country to another were, by ship round the coast, by barge on the canals, or by wagon on the roads. Heavy goods could be transported much more quickly and easily by canal than by road; and the total length of the navigable canals constructed in Britain in the century just before the invention of a satisfactory locomotive steam-engine, and the birth of the present railway system, was nearly four thousand miles.

The idea of making a tunnel which should be a roadway was of still later growth, and came about in this manner. Below London the Thames widens very greatly, ebbing and flowing as a tidal river between low banks. To throw across such a stream a bridge of sufficient height to allow of the passage of ships to and from London, was too difficult and too expensive to be dreamt of at that time; and yet it was felt that a direct road from bank to bank was extremely desirable. Without it, all goods going from Kent to Essex, or from Essex to Kent, had either to be carried round by London Bridge, or loaded into barges and ferried across the river.

An eminent north-country engineer, named Ralph Dodd, was the first to point out the usefulness of a tunnel under the Thames from Tilbury to Gravesend. If you look at a map of England, you will see that such a tunnel would have formed an important link between the two counties. The width of the Thames, however, was here over half a mile; and when the plan was put before the public, it was thought impossible to drive a tunnel of that length through the mud and shifting sands underlying a tidal river.

Four years later — in 1802 — Mr. Vazie suggested that a useful tunnel might be driven under the Thames between Rotherhithe on the south bank, and Limehouse on the north. This scheme seemed to many people much more promising than that of Mr. Dodd; and a number of enterprising gentlemen formed a company and subscribed sufficient money to commence the work.

Vazie's idea was to make first a drift-way or drain, of small diameter, seventy-six feet below high-water mark, from side to side of the river. This would afterwards form the necessary drain at the bottom of the tunnel itself; and, during its excavation, the character of the beds through which the tunnel would have to be driven would be ascertained.

He began, therefore, by sinking a shaft on the bank of the river. This shaft, which was eleven feet across, had been taken to a depth of forty-two feet, when the water broke in through a stratum of gravel in such volume that the pumping-engine could not cope with it. This accident checked the progress of the work, as the shaft was soon filled almost to the brim.

The promoters were dismayed at such a disaster; and, as they had already spent about seven thousand pounds, they were unwilling to risk any greater loss. After much persuasion on the part of Mr. Vazie, however, they consented to continue. A sort of water-tight lining was constructed for the part of the shaft which passed through the bed of gravel, and the shaft itself was carried down to the depth intended—seventy-six feet.

But the bursting in of the water had given the promoters a fright, and, before they would allow Mr. Vazie to commence driving his trial tunnel, they engaged another eminent engineer, Mr. Trevithick, to superintend the whole work. This was in the summer of 1807; and by the beginning of autumn a drift-way, five feet in height, three feet wide at the bottom, and two feet six at the top, had been carried about one hundred and thirty yards under the river.

Disputes now arose between Vazie and Trevithick; and, although Mr. Vazie had planned the whole work and had spent four years in trying to carry it out, he was dismissed.

Trevithick became sole manager, and by Christmas had finished nearly three hundred and twenty yards. A few days before Christmas the workmen broke into a quicksand which caused considerable trouble; and to add to the difficulties the roof of their passage fell in repeatedly.

Towards the end of January, 1808, when over three hundred and forty yards had been driven, the soft ground between the drift and the Thames gave way, and the water rushed in. A hole was scoured out by the water in the bed of the river, and it was evident that before anything more could be done this hole must be filled up. Countless bags were filled with clay, carried out in barges, and flung in, the spaces between them being packed with earth and gravel.

As soon as the hole was plugged, the pumps were started, and the drift once more cleared of water. Then the work of driving the passage was restarted; but, when rather more than twenty yards had been added, the river broke in again, completely filling the tunnel and shaft in less than twenty minutes.

Once more the hole was plugged with bags of clay, the water was again pumped out, and the workmen managed to add about twenty feet; but the water rushed in so often and with such violence, that at last they were compelled to abandon the attempt to drive their passage to the other bank.

Five years of hard and dangerous labour had given no practical result; a large sum of money had been spent in vain. Some of the ablest engineers in the kingdom expressed their opinion that to make a subway under the Thames of any use to the public, or likely to be profitable to those who spent their money in constructing it. was impossible.

So the matter remained for fifteen years, till the master-mind of Marc Isambard Brunel tackled the problem and solved it. Strangely enough, Brunel was not an Englishman; he was one of those unfortunate Frenchmen belonging to the upper classes, whom the excesses of the leaders of the Revolution drove from their own country, to the infinite gain of those peoples among whom they took refuge, and to the irreparable loss of France.

Brunel's life-story is so interesting, and shows so finely how a man of character and purpose can rise, even in a foreign land, above the misfortunes that threaten to overwhelm him, that it is worth while to present a short account of his earlier years.

He was the son of a Norman gentleman living not very far from Rouen, the beautiful city on the Seine which, once the capital of Normandy, is now called the "Manchester of France" because of its importance as the chief seat of the French cotton manufacture. His father intended that he should become a priest of the Roman Catholic Church, and sent him to receive at the College of Gisors an education which would fit him for that vocation. Young Brunel, however, hated the classics and loved working with tools. Whenever he could steal away from his distasteful studies, he hurried to some workshop to watch, or, if possible, take part in, the work being carried on.

He displayed at a very early age a talent for drawing and painting; and, added to this, he possessed the faculty of being able to fashion in wood a copy of any piece of mechanism which took his fancy.

It became at last evident, even to his father, that he would never make a priest. When he was asked what he would like to become, he said at once, "Make me an engineer." His father, however, thinking very little of that profession, chose instead for him that of a naval officer; and he was sent to Rouen to take up the proper course of study.

The navy of France was at this time more powerful and more efficient than it had ever been before—or, comparatively speaking, than it has ever been since. Louis XVI., whatever his faults may have been, did his utmost to increase the sea-power of France; while, under the Georges, the maritime strength of Britain was permitted to decline, till the sharp lessons of the war with the American colonies were taken seriously to heart. It is not too much to say that, had not the fleets of France been able to hold the seas against Britain, and so to render assistance to the rebellious colonists, the American States could not have won their independence.

While Isambard was at sea, the Revolution commenced; and the people of France were divided into two warring sections—those who supported the old style of government, and those who desired an altogether new order of things. Brunel, like most of his class, was an ardent royalist, and took no pains to hide that fact. His ship being paid off in 1793, when he was about twenty-four years of age, he went to Paris. Here his outspoken loyalty to the imprisoned king, soon to suffer death by the guillotine, brought him into peril, and with difficulty he escaped to Rouen.

At Rouen he became acquainted with Miss Kingdom, a young English lady who six years afterwards became his wife. Her position and his own were full of danger. The "Reign of Terror" had begun in Paris; and even in the provincial cities no one suspected of being a royalist was safe. Miss Kingdom was seized and put in prison—luckier in this than two poor girls of the same city, who were murdered by the mob because they had played upon the piano a loyalist tune—and Brunel fled to America, hoodwinking the naval officers with a false passport.

He was now thrown entirely on his own resources in a strange country—for, of course, his commission in the French navy was forfeited by his flight. He was fortunate enough, however, to secure work as an assistant to two French surveyors, who, with four Indians to guide them and to assist in procuring food, were about to explore a portion of the wild forest land in the north-west of New York State.

Returning from this expedition, the three surveyors were requested by a prominent citizen of New York, Mr. Thurman, to undertake the survey of the country through which it was intended to cut a canal from the Hudson River to Lake Champlain.

This was Brunel's opportunity to show his engineering genius; and he made the best possible use of it. So remarkable was the ability he brought to bear upon this and other schemes for improving the internal navigation of the state, that, in little more than a year, he had made a name for himself and was earning large sums of money. Amongst other things he drew the plans for a fine theatre, thus showing himself in a new light as an architect; and, as chief engineer to the city of New York, he erected a cannon foundry and constructed a considerable number of guns.

During the whole of his residence in America, however, his thoughts and hopes had turned ever to England, where Miss Kingdom, released from prison, was now residing with her family. From boyhood he had longed to visit England, the land of skilled workmen, little knowing that the greater portion of his life would be passed in this country, and that he and his son would rank in history as two of England's eminent engineers.

He landed in Cornwall in the spring of 1799, and was soon afterwards married to her for whom his affection had never wavered. How much a good wife can help her husband was never more clearly shown than in the case of the Brunels. "To you, my dearest Sophia, I am indebted for all my success," he wrote forty-six years after his wedding-day.

It was not long before his inventive genius brought him to the notice of the British public; but that which gained him fame and fortune was his invention of the marvellously intricate machinery for the making of the blocks used in the rigging of ships—machinery which was judged to have saved the British admiralty more than sixteen thousand pounds a year.

It is impossible to follow step by step in so short a sketch the career of this wonderful man. A mere list of all his labour-saving inventions would occupy considerable space. Amongst others were machines for bending timber, for cutting thin slices of valuable woods to be used as veneers, and slices of hard woods to be converted into hat-boxes and pill-boxes; improvements in sawmills; a remarkable system of underground water-way, shaft, and steam-engine by which the timber used in building warships was brought from the river into Chatham dockyard; and a machine for making army boots, which produced four hundred pairs of capital boots per day.

A double-acting marine steam-engine, a knitting-machine, a new method of making tin-foil, and improvements in printing-presses were a few of the inventions of Brunel's fertile brain in the years leading up to 1824, when he commenced the greatest of all his works—the construction of a tunnel under the Thames.

These years had not been altogether happy ones for him. The close of the war with France stopped the demand for army boots, and the large stock which Brunel had on hand was sold at a loss of three thousand pounds.

His sawmills were burnt down, and the firm of which he was a partner, being unable to meet its payments, became bankrupt. Brunel was arrested for debt in 1821, and thrown into prison; but, through the efforts of his friends, a sum of five thousand pounds was granted to him by the government in consideration of his services to the country.

We next find him in charge of the timber-lifting machinery at Chatham, designing saw-mills for the West Indies, and a suspension bridge for the Isle of Bourbon in the Indian Ocean, besides swing-bridges for the Liverpool docks. It was Brunel, by the way, who suggested the floating landing-stage, which has made safe and easy the transfer of passengers to and from vessels at any state of the tide.

The project of uniting by means of a subway the two banks of the Thames appealed strongly to Brunel's mind; and, as early as 1816, we find him thinking of ways of solving the problem that some of the best engineers of the day had declared to be unsolvable. It is said that the method which he afterwards employed was suggested to him as he was examining the ravages committed by the common "ship-worm," upon the timbers of sea-going vessels.

The ship-worm is a kind of mollusc or shell-fish, clinging to the wood with a sucker-like foot, and boring its way in by means of the two valve-like shells which cover the forepart of its body. These shells it moves or rotates as a cork-borer is moved, gradually making its way into the timber. Its foot, or sucker, has an opening through which the pieces of wood detached by the action of its shells are passed back to its organs of digestion.

As he studied this creature, the thought occurred to Brunel that here was Nature's lesson to man upon the perfect method of boring through soft or watery earth. He saw that a ring-like shield, resembling the shells of the ship-worm, would keep the yielding walls and roof from falling upon the miners working within it, and that, as quickly as it was pushed forward, the tunnel might be lined with a double arch of brick-work, just as the hole bored by the mollusc is lined by the creature with a hard, shelly substance.

The shield, however, was the main idea; and in 1818 Brunel took out a patent for a boring machine made on this principle. The shield was to be cylindrical, and made to rotate and move forward by means of water-power. The engineer found, however, that the cylindrical form was not a good one, and he finally decided upon a system of rectangular cells, the working of which may perhaps best be explained by a simple illustration.

Suppose yourself to have thirty-six match-boxes. Take out from each the sliding tray which holds the matches, and pour the matches into a big jar out of the way. In order to represent Brunel's cells perfectly, these trays should be rather more than twice as long as they are wide, as the cells were three feet broad and a little over seven feet long; and they should be much deeper. Now, take three of the trays, set one of them on its shorter side like a little sentry-box, place the second upon it in the same position, and the third upon the second. You have now a triple sentry-box, three storeys high. Fasten these three cells together by means of paper-pins, and proceed in the same way till you have twelve sets of cells, each three storeys high, standing side by side. You will see that the whole machine consists of thirty-six cells, and that its total width will be thirty-six feet, plus the thickness of the partitions, while its height will be rather more than twenty-one feet. To complete the illustration, imagine that a miner is standing in each of these thirty-six cells, ready to begin work.

The backs of the cells which pressed against the earth to be excavated were not, as in the match-boxes, made in one piece. They were formed of boards, each six inches wide and three inches thick, and, of course, since they stretched from side to side of the cell, three feet in length. These fourteen boards, or thereabouts, forming the back of the cell, were each kept in place by means of two jack-screws, one end of which pressed against the end of the board, and the other against the front rail of the cell.

Let us suppose now that boring or driving is just about to begin. A strong arch has been built to support the mouth of the tunnel, and against this press the ends of large jack-screws, the other ends pressing against the frame-work of the cells. The problem is to move forward in turn the frames enclosing each set of three cells, without disturbing the boards at the back, which are keeping the earth from tumbling in.

Suppose we begin with the frame farthest to the left. The jack-screws are one by one slackened, moved so as to rest in notches on the neighbouring frame, and tightened up again. The frame is now free, and can be forced forward into the yielding earth by means of the powerful jack-screws already mentioned. The roof of the uppermost cell is composed of three narrow iron plates, called staves, each of which can be pushed forward in turn, at any rate we please; so that there is always a strong roof over our heads. Each of the twelve frames is pushed forward in turn, the whole machine thus advancing steadily.

Standing with his back to the miner is a bricklayer, busily continuing his arch as fast as the machine is pushed forward, thus making all safe and strong. All that the miner has to do is to take down the boards one by one, dig out the earth behind till he has reached the point to which the frame has been pushed, and then put up the board again, securing it with its two jack-screws. The earth which he digs out will be taken away by labourers.

You can see that progress will be very, very slow, but that the men will work in comparative safety, and that every inch gained will be made secure and permanent by the brick lining.

A company was formed to carry out Brunel's scheme, a sum of five thousand pounds being paid to him for the use of his patent, and a salary of one thousand pounds a year guaranteed for three years, by which time it was expected that the work would be completed. This was in 1824, and the tunnel was not finished till 1842!

Brunel began by sinking a shaft on the south bank of the river at Rotherhithe. This shaft was to be fifty feet across and forty-two feet in depth. As the ground was much too soft and spongy for ordinary methods of sinking, Brunel built up a cylinder of brick-work resting on a ring or curb of cast-iron; and then his workmen, going down inside, cut away the ground from under it, letting it sink gradually by its own weight—over nine hundred tons—till it formed the lining of a shaft. When it had sunk forty feet into the earth, it was fixed firmly by means of what is known as "underpinning"—removing the earth from under the edge section by section, and replacing it with solid masonry. This underpinning was carried down to a depth of twenty feet below the bottom of the cylinder, a hole thirty-seven feet wide and twenty-two feet high being left at the north side to receive the shield; so that, when finished, the shaft was rather more than sixty-two feet in depth.

The sinking of the cylinder took nearly three months, and was not accomplished without numerous alarms and difficulties. Once it seemed as though the tower, through one side sinking more rapidly than the other, would fall over or break to pieces; on another occasion the water overpowered the efforts of the men to bale it out, and rose fifteen feet. It was not until a pumping-engine had been got to work that any further progress could be made.

Towards the end of November, 1824, the actual driving of the tunnel began. Seventy-two miners were engaged to work in shifts of eight hours, thirty-six in each shift, besides a large number of bricklayers and labourers.

The hole made by the miners was to be

thirty-seven and a half feet wide, and twenty-two feet in height; and into this was to be built a thick mass of brick-work, leaving two parallel arched roadways, each fourteen feet wide and seventeen feet high.

Mr. Brunel was prevented by serious illness from being present at the beginning of the boring; and his son, Isambard Kingdom Brunel, a young man not yet twenty years of age, but destined to become in the future as famous an engineer as his father, took charge of the enterprise.

By the middle of May, 1825, one hundred feet had been completed, in spite of trouble caused by the breaking in of water, and sometimes of soft earth. Two hundred feet had been constructed by the middle of August, in which month a very capable engineer, Mr. Beamish, was engaged to assist Mr. Brunel and his son.

The second week of September brought an alarm from the bursting in of liquid mud through the back of the shield. Neither Brunel nor his son slept much during that week; but the danger was finally averted and the difficulty overcome.

A remarkable thing was the confidence shown by the men in the safety of their position, driving a tunnel through semi-liquid earth under a river which, had it not been for the shield, might have broken in at any moment and flooded both tunnel and shaft.

What a strain it must have been upon Mr. Brunel can be seen from this brief extract from his diary: "For nine days, on an average twenty and one-third hours per day in the tunnel, and three and two-thirds to sleep."

The work went steadily on until May 18, 1827, when a tremendous irruption of water occurred, flooding the whole of the workings. One man was with difficulty saved from drowning, by the readiness of young Mr. Brunel.

There had been many warnings that such an accident was likely to occur, and Mr. Brunel's diary shows that he was often nervous about the safety of the visitors who persisted in coming down to inspect the work. A more sinister warning than any that had gone before was given by the recovery, from the ground in front of the shield, of a shovel and hammer dropped into the river from a diving-bell three weeks previously.

It was over two months before the men could once more walk to the frames, though they had reached them by boat several times and found them still holding firmly. The hole in the river's bed was filled with bags of clay pierced by hazel rods, and thus the influx of Thames water was arrested. The pumps were set to work and the water was at last got under control.

In spite of various alarms the operations now went on satisfactorily till nearly the middle of January, 1828, when about six hundred feet of the tunnel had been finished. The water then broke in with such violence that several men were drowned, and young Mr. Brunel was seriously injured in trying to save them.

The hole was again filled with bags of clay—four thousand five hundred tons of it—and Brunel was once more ready to carry on the work. But the funds of the Company were now completely exhausted; and the shield was at last built in, and further progress abandoned for seven years.

Mr. Brunel was of opinion that the action of the directors of the Company in insisting upon piece-work, in order to hurry the men forward, had made the task much more difficult and much more costly than was necessary.

An attempt was made to raise money from the public in order to complete the work; but though many eminent men, including the Duke of Wellington, were in favour of this scheme, the funds were not subscribed.

So, for seven years, the unfinished tunnel was simply one of the sights of London. It became a favourite promenade, being lighted with gas, and well ventilated.

At last the government was induced to

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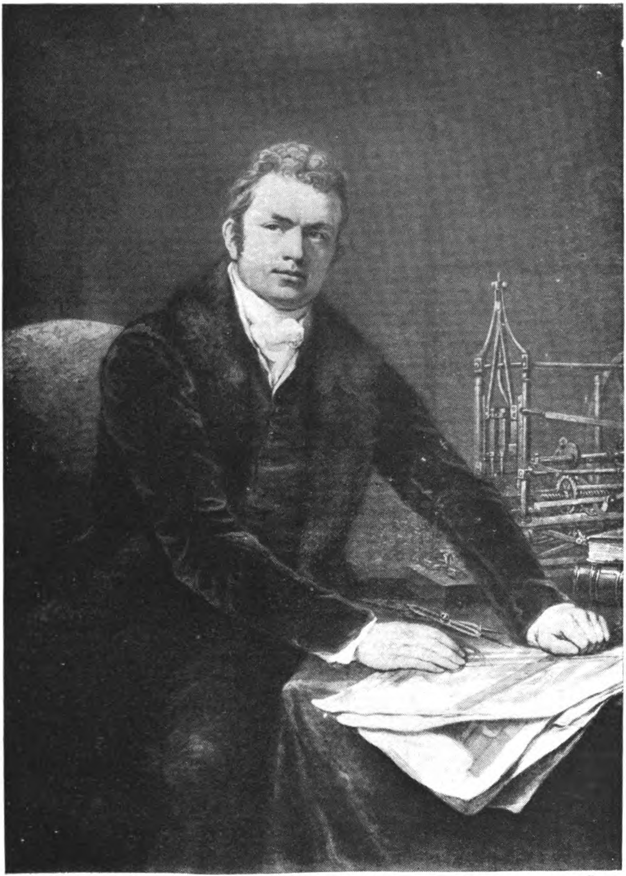

P.P. Sir Marc Isambard Brunel. C

guarantee to the Tunnel Company a loan of two hundred and forty-six thousand pounds, and the work was resumed. In spite of serious difficulty and danger the old shield was removed, and a new shield of an improved design put in its place.

The old troubles were met with again, and overcome by skill and pluck. Sometimes as much progress as twenty feet in a month would be made; at other times six or seven feet only were added in a similar period. During the winter of 1837-38, the river broke in three times, and another life was lost. Poisonous and explosive gases escaped from the ground into the tunnel, the men sometimes falling senseless in their cells.

Year followed year, but still the work went steadily on until August, 1840, by which time the tunnel had been taken to within sixty feet of the position of the projected shaft on the north side. This shaft had now to be built and sunk.

Profiting by his former experience, Brunel made the tower, which would afterwards become the lining of the shaft, much higher and heavier than that on the south side of the river. It was two thousand tons in weight, seventy feet in height, and fifty-five feet across. Its building occupied thirteen months, and it was sunk into the ground in the same way as that at Rotherhithe.

Before the rest of the tunnel was begun, Mr. Brunel was knighted by Queen Victoria, in recognition of his long-continued and able services to his adopted country.

The joining of tunnel and shaft was a labour of anxiety and difficulty, but was successfully completed by the 7th of January, 1842. Much, of course, still remained to be done. Spiral staircases for the ascent and descent of the shafts had to be constructed; the arrangements for ventilation and drainage had to be perfected, engines removed, and the approaches made; so that it was not until the 25th of March, 1843, that the tunnel was opened to the public.

You may judge of the wonder and interest displayed by the people of this country and by foreign visitors, when you are told that the number of persons who walked through the tunnel during the first Saturday evening and Sunday was fifty thousand; while in fifteen weeks more than one million had visited it.

The tunnel was purchased in 1865 by the East London Railway Company, and now forms an important link between the lines on the north, and those on the south side of the river Thames.

Sir Marc Isambard Brunel lived only a few years after the completion of his work, dying in 1849 at the age of eighty-one.

The "shield" system invented by him, and used in this first Thames Tunnel, is still employed in driving tunnels through soft or loose earth, though it has been made much safer and quicker by the use of an iron lining, together with the employment of compressed air to keep out water and mud.

In the making of the Blackwall Tunnel, begun in 1892, and opened by our present King, then Prince of Wales, in 1897, the workmen were enclosed in an air-tight chamber, into which a powerful engine pumped air at a pressure of fifty pounds to the square inch. So effective was this enormous pressure that not only was the tunnel kept clear of water, but occasionally the air forced its way through the bed of the river, throwing up a column of water fifty feet in diameter to a height of twenty-five feet. The cost of this tunnel was over three-quarters of a million pounds.

Other important subaqueous tunnels in England are the Severn Tunnel, over four miles in length, and the Mersey Tunnel, a mile and a half in length. There are, of course, many land tunnels; but since these are in the main driven through hard rock, a detailed history of their construction would be out of place in this little sketch.

The wonderful railway tunnels which pierce the Alps show to what perfection the art of tunnelling through hard rock has been brought.

You may perhaps be surprised to know that a tunnel through the chalk under the sea from Calais to Dover was begun in the year 1872, and driven out for two thousand yards from each end, when further progress was forbidden by the British Government.

The project of connecting France and England by a submarine tunnel was first suggested by a Frenchman, M. Matthieu. When Napoleon was chafing at the impossibility of invading England because of the British fleet, this engineer offered to make a road under the Channel. His suggestion, however, does not seem to have aroused any enthusiasm in the Emperor's breast.

Other schemes have since been mooted, such as the laying of a great railway-tube on the bed of the sea, or the construction of two parallel single-line tunnels; but the experimental borings of the English Channel Tunnel Company already mentioned form the only practical outcome of all these suggestions.

That the making of such a tunnel is within the power of modern engineers is quite certain; but British military authorities are opposed to it, as its existence would render the defence of this country much more difficult.

II. Alan Stevenson.

HAVE you ever tried to realise the feelings of a sailor towards the lights that shine out in the darkness, from the rock-bound shores past which his vessel is hurrying to the port for which she is bound? Can you imagine the affection that stirs in his heart for the beacon signalling to him through the mirk of a stormy night? "Have a care, friend," it seems to say; "there are cruel teeth around me, waiting to fasten in a death-grip upon your ship if you venture too near." Or its welcoming beam may tell him that the longed-for harbour is open before him, and that the end of his weary voyage is at last in sight.

It is a most impressive experience to sail at night past a sleeping land, and to pick up one after another the lights along the shore. Every one is known to the skilful mariner—he can distinguish each by its own arranged peculiarity—one by its steady, unwavering radiance, another by the number of seconds between its flashes, or the colour or quality of its light.

The thought that each light is watched and tended by an unsleeping guardian gives a feeling of comfort and companionship to the lonely lookout in the bows of the vessel, and to the anxious officer pacing her bridge. On shore are loving, tender hearts to which his safety is a matter of solicitude; he knows that everything is being done, so far as human effort and will can accomplish it, to guide him on his path, and to give him warning of the perils with which it is strewn.

The history of the erection and keeping of lighthouses furnishes many a stirring page; many deeds of heroism and self-sacrifice are recorded in the annals of Trinity House and of the Commissioners for the Northern Lighthouses. Some of these stories are so thrilling that they have been retold in popular form by many a story-writer; and they serve a useful purpose in showing the unswerving devotion to duty of those to whom has been entrusted so great a responsibility.

The annual toll of life and property exacted by the sea is sorrowfully large; but who can say how much greater it would be, were it not for the wisdom and skill of those who have set the lights at the points of danger or difficulty, and for the unwearied care and attention of those who tend them?

From the earliest times beacons have been used as signals or warnings to sailors. Three hundred years before the Birth of Christ, a fire, burning nightly on the summit of a tower on the Island of Pharos, guided mariners to the shore of Egypt and the port of Alexandria; and there is some probability in the ancient legend that the Colossus of Rhodes — that mighty brazen statue which bestrode the entrance to the harbour of Rhodes, and allowed ships to enter between its feet—carried, either on its head or in its hand, a fiery signal to seamen approaching the coast.

Another historic lighthouse was that at Coruña, in Spain—near the spot where Sir John Moore was buried after his brilliant defeat of the French. This lighthouse is believed to have been built in ancient Roman times, as a guide to sailors from Ireland trading with Spain.

There was another beacon tower on the coast of Spain from very early times. This was a stone tower built on a wave-washed rock near the mouth of the Guadalquiver, to guide vessels through the dangerous shallows of the estuary.

When a vessel is sailing at night through the Strait of Dover, the lights along the French and English coasts are alike clearly in sight, shining like friendly blinking eyes through the darkness. From a very early date, indeed, lights have shone out over the waves of the English Channel. An ancient tower at Dover, now completely ruinous, and known as Cæsar's Altar, faces a similar ruin at Boulogne, on the coast of France, known as the Tour d'Ordre. These are believed to have been lighthouses erected to guide the Roman vessels from Gaul to Britain.

During the Roman occupation of Britain a special officer was appointed to ensure the protection of the eastern coast from the bold raids of the Scandinavian sea-robbers. This officer was known as the Count of the Saxon Shore. It seems likely that he patrolled the coast with a naval force large enough to repel the raiders ; and, on Flamborough Head, are still to be seen the remains of the lighthouse or "Pharos," which acted as a guiding beacon to his fleet.

These ancient lighthouses were, of course, not to be compared with the present magnificent structures. Their light was given by means of a fire of wood on the top of the tower, by the burning of sticks dipped in tar, or, in later times, by the flaring of a fire of coals. So late, indeed, as the date of the accession of George III. to the throne of Great Britain, the open coal fire was the only sea-light used round the coasts of Britain, except in the Eddystone Lighthouse, and the lighthouses of the port of Liverpool. The lighthouse on St. Bee's Head, in Cumberland, was the last where coal fires were used, oil lamps being introduced in the year 1823.

The lights on the French coast have the name amongst sailors of being some of the finest in the world ; and the Tour de Corduan, standing on a dangerous reef at the mouth of the Garonne, is the grandest lighthouse in existence. It consists of a mighty tower, one hundred and ninety-seven feet in height, gallery rising above gallery, each with the most beautiful decoration of pilasters and friezes, till the cone at the summit is reached, and the magnificent lantern which serves as a guide to the shipping along many a mile of dangerous coast. The tower itself contains a chapel and many spacious rooms, a wide and well-constructed staircase leading from chamber to chamber.

This magnificent lighthouse took twenty-six years to build, being finished in the year 1610, during the reign of Henry IV.—Henry of Navarre, as he was often called. Billets of oak, burning in a specially-constructed grate on the summit, were for many years employed to give the required light ; but coal was afterwards used. Lamps were first placed in it in the year 1780; and since that date improvement after improvement has been effected, culminating in the splendid light which now shines nightly over the stormy waters of the Bay of Biscay.

On the Eddystone four lighthouses have succeeded each other. This dangerous ridge of rock, standing directly in the fair-way of vessels bound for Plymouth, had for ages caused so many disasters that, in 1696, a beginning was made with a lighthouse which should warn mariners of their position. The difficulties to be faced were numerous. The exposed surface of rock was of small extent, and seldom unwashed by the mighty waves rolling in from the open Atlantic—even in perfectly fine weather the waves dashing upon submerged rocks round the main reef rise to a height of thirty or forty feet. The reef stands at a distance of fourteen miles from Plymouth, and over nine from Ramhead, in Cornwall; so that the conveyance of material and food to the workmen was always a troublesome business, and was made worse by the difficulty of landing upon the reef.

However, in 1696, a gentleman of Essex, Mr. Henry Winstanley, managed to fix in the hard gneiss of which the reef is formed twelve massive iron stanchions, building round them in the second year a heavy mass of masonry. On this foundation he erected during the third year a tower of wood and stone, eighty feet in height and eighteen feet in diameter. The tower contained rooms for the keepers, and at the summit was the welcome light, which first cast its gleam over the waters on the 14th of November, 1698.

So much greater, however, was the strength of the waves than had been expected, and to so great a height did they rage, that it was found necessary to build a wall four feet in thickness round the tower, and to carry it up to a height of one hundred and twenty feet.

For five years the lighthouse braved the fury of the sea; and so firm was the faith of its builder in the security of his work, that he is said to have wished that he might be in the lighthouse during the greatest storm that ever blew.

His confidence, however, was ill-founded; for, while he and his workmen were carrying out some repairs during November, 1703, a dreadful storm swept away the whole erection, Mr. Winstanley and his assistants perishing in the waters.

Soon after this calamity a British man-of-war was wrecked on the rock; but three years passed before a beginning was made with another lighthouse. This was erected by Mr. Rudyerd, a silk-merchant of London, and was built of alternate courses of heavy timber and stone, all securely bolted together and to the rock itself. Outside this inner core was a sheathing of heavy timbers, fastened to the oak courses and to each other, the seams being caulked with oakum and pitch like those of a ship. The light was given by twenty-four candles, each one-third of a pound in weight.

This structure stood for forty-seven years, and was then accidentally burned down. But for this unfortunate occurrence it might have lasted many years longer, being evidently well able to resist the force of wind and wave.

A third lighthouse was begun at once, the erection of it being entrusted to Mr. John Smeaton. Smeaton determined to build his lighthouse as nearly as possible in the form of the trunk of an oak, being convinced that Nature gave that form to the tree to enable it to resist the enormous pressure of the wind upon its wide-spreading branches.

He also decided that a building entirely of stone was better than one partly of timber, not only because it would be fireproof, but also because the greater weight would make it stand more securely upon its foundation.

The building was begun in June, 1757; but more than a year had already been spent in preparing the foundations and the stones for the first courses. The first twelve feet were of solid stonework, the blocks being securely dovetailed into each other and the rock, so that, when the cement between them had set, they would defy any force of wind or sea to tear them apart. The total height of the tower was sixty-eight feet.

In the lantern candles alone were used until 1807, when good oil-lamps with reflectors were substituted for them.

Smeaton's lighthouse thoroughly justified its builder's confidence in its stability, standing securely from its completion in 1759 until it was taken to pieces in 1882, and re-erected on Plymouth Hoe as a worthy monument to the memory of the man who designed it. It was not taken down because it had failed in any way, but because the rock upon which it was built had been so far undermined by the sea, that it was no longer safe as the foundation of so weighty a structure. A new lighthouse—the fourth—was therefore built upon a stronger portion of the reef, the old tower continuing to send out its nightly warning while that which was to replace it rose steadily, course by course, beside it.

The rock upon which the new tower was built is under water at high tide; so that the first stages of the work were exceedingly difficult and dangerous. Upon this rock was built first a solid cylinder of stone, twenty-two feet in height and forty-four feet across. On this platform was set the tower, tapering from thirty-five and a half feet in diameter at the base to eighteen feet six at the top, the cornice below the lantern being one hundred and thirty-eight feet above the rock.

The light, which is visible at a distance of over seventeen miles, is a double-flashing white light, each flash lasting two seconds and a half, the two flashes occurring every half-minute. In foggy weather, when the light cannot be seen, an enormous bell, weighing two tons, booms out two quick strokes every half-minute. This fourth tower is the work of Sir James N. Douglass, and is built almost entirely of Cornish granite.

Another famous lighthouse is that built upon the Inchcape Rock — or Bell Rock, as it is often called. Most of you have read Southey's ballad, *The Inchcape Rock*, telling how Ralph the Rover met the fate he had prepared for others. This ballad is founded upon a well-known tradition from which the name "Bell Rock" is derived.

The Bell Rock Tower was built by Mr. Robert Stevenson, a famous Scottish lighthouse builder, and the father of the subject of the present sketch. It is altogether one hundred and fifteen feet in height, the first thirty feet being solid, and is remarkable for its revolving red and white light, and its two great bells. The cost of building this lighthouse was sixty thousand pounds.

But by far the most remarkable feat of lighthouse construction carried out successfully in modern times, was the erection of the tower on Skerryvore.

Turn to the map of Scotland, and you will see amongst the Hebrides the island of Tyree lying with its companion island of Coll between Mull and Barra. Fourteen miles to the west-south-west is a group of rocks, the largest of which is known as Skerryvore. The ridge, which stands well out in the Atlantic, was a source of terrible danger to vessels making for the Clyde and the Mersey, if they happened to be carried north of their proper course; but it was felt that the erection of a lighthouse would convert it into a most convenient guide instead of a constant peril.

As early as the year 1804, Robert Stevenson landed on it to make a survey for the Northern Lighthouse Board, for whom he acted as engineer; and in 1814 he again visited it with a committee of the same Board. With them was Sir Walter Scott, the novelist and poet, who gives in his diary an amusing account of their landing. He speaks of the tremendous surf continually dashing over the reef, and of the difficulty experienced in landing on any part of it. He finishes by saying: "It will be a most desolate position for a lighthouse—the Bell Rock and Eddystone a joke to it, for the nearest land is the wild island of Tyree, at fourteen miles distance."

In spite of the danger of the undertaking, it was plain to every one that a lighthouse must be built somewhere on the reef. Between 1790 and 1830, twenty-one vessels are known to have foundered or been hurled to destruction in the immediate neighbourhood; and, before the light at last shone out over the wild Atlantic, ten more had perished there.

A beginning was made by the Northern Lighthouse Board in 1834, when Mr. Alan Stevenson was instructed to make a complete survey of the rocks, and to report as to the expense of erecting the tower.

Mr. Stevenson was then only twenty-seven, having been born in the year 1807. He was the eldest son of the Robert Stevenson with whom Sir Walter Scott had visited Skerryvore, and

Alan Stevenson.

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had greatly distinguished himself at the High School and the University of his native city of Edinburgh. At the University he not only obtained the degree of Master of Arts, but also won the Fellowes prize as an advanced student in Natural Philosophy.

It was at first intended that he should take Holy Orders; and with this purpose he studied for some time with a clergyman at Twickenham. He was a remarkably keen student of languages, reading with ease and pleasure Greek, Latin, French, Spanish, and Italian, studying the literatures of these five tongues besides that of his own island.

After a while, however, he decided to follow his father's profession—that of a civil engineer—and became a pupil in his father's office. Here he proved so valuable an assistant that before long he became a partner in the business, and was entrusted with the carrying out of much important work, such as the designing and building of piers, the improvement of harbours and of river-mouths, and the building of sea-walls.

In 1830, at the early age of twenty-three, he was admitted a member of the Institution of Civil Engineers. A civil engineer, most of you know, is one to whom is entrusted the designing and carrying out of such things as embankments and dams, the formation of harbours, the building of bridges, the making of roads and railways, the sinking of mines, and other useful works of a like nature.

The Lighthouse Board having decided upon erecting a tower on Skerryvore, no time was lost in making a beginning. So broken was the weather, however, that, though the survey was commenced in the autumn of 1834, it was not finished until the summer of the next year. Nor does this seem wonderful, when we read the engineer's own account of the rocks and the wild sea surrounding them. In the strait between Tyree and the first rock of the Skerryvore group—Boinshly—no vessel can live in a gale; sometimes it is white with foam from island to rock. On Boinshly itself the sea dashes continually, the spray rising sometimes like a mighty fountain.

One point of difficulty was the finding of a secure foundation, and, after examining with the greatest care all the rocks of the group, Mr. Stevenson decided that on Skerryvore alone—"The Great Rock," as the name means in Gaelic—could be found a suitable site. Even here, the available space was only about one hundred and sixty feet by seventy feet, so much was the rock cut up and undermined.

Another difficulty, small in itself, perhaps, but exceedingly troublesome, was the ice-like smoothness of the wet stone. One workman, who had slipped and fallen in landing, likened it to climbing up the side of a bottle.

The greatest difficulty of all, perhaps, was that caused by the distance of the reef from the mainland. The nearest land was Tyree; but Tyree had no harbour, and the people, poor peasants and fishermen, could scarcely win from the sterile soil and the wild sea sufficient food for themselves and their families. Even the turf used for fuel had to be brought from Mull, across nearly thirty miles of turbulent water—and yet, in 1841, Tyree supported a population of nearly five thousand souls! Its inhabitants now number hardly two thousand.

It was certain that everything required by the builders of the lighthouse would have to be brought first to Tyree—except, fortunately, stone. But, if ships were to land stores on Tyree, a harbour of some simple sort must be constructed—a harbour which could afterwards serve as a shelter to the vessel detailed to attend to the needs of the lighthouse-keepers.

For this purpose the creek of Hynish, as short a distance as possible from the rock, was chosen. A quarry was opened in the hard gneissic rocks round the creek, the big blocks being prepared for the building of the lighthouse, and the less suitable ones dropped into the sea to form the foundation of a pier.

Meanwhile, a steamer was being built at Leith to act as a tender, and preparations were in progress for the erection of a wooden barrack or shelter on Skerryvore itself. In this Mr. Stevenson followed the example of his father when building the Bell Rock Lighthouse. The purpose of the temporary barrack was to enable some of the workmen to remain upon the rock, and so prevent the waste of time caused by bringing them to and from Hynish—a trip always risky, and in some states of the weather impossible.

The barrack was in itself quite an imposing structure. It consisted of an open pyramidal framework of six logs, forty-seven feet in length from the rock upon which they were planted wide apart to the summit, where they were joined. These logs were strongly fastened together, and supported a turret thirty feet high and twelve feet across. The lowest room was to be the kitchen and bread-store, and one above it, divided by a partition, was to afford sleeping accommodation for Mr. Stevenson, the foreman of the works, and the landing-master. The third storey was fitted with bunks for thirty workmen, and at the top of all was a small lighthouse lantern.

The barrack was made at Greenock, the different parts being carefully fitted together, and then taken apart for shipment to Skerryvore. The early part of the year 1838 was occupied by the preparation of all the varied stores, implements, cranes, trucks, chains, and workyard materials; and June was nearly ended before a real beginning could be made with the setting up of the barrack on the rock. Thirty granite-masons, twelve quarrymen, and some smiths were engaged upon a two years' agreement; and the work of quarrying and preparing the blocks for the tower, which had been proceeding for about fifteen months, was now carried on with increased vigour.

All, however, that could be done on the rock was to mark out with white paint the position which tower and barrack would take, where the cranes should stand, and where the ring-bolts should be fixed. Then for another month the engineer was busied in collecting at Greenock and Glasgow cranes, boats and coals, grindstones, pavement, stucco, clay and shear-legs, and despatching them to Hynish.

At Hynish the work proceeded satisfactorily.

Houses for the workmen were being built, blocks quarried and dressed, and the pier was being carried out farther into the creek.

On the 7th of August a full day's work was done on the rock itself. So severe had been the weather that neither the *Pharos*, the sailing vessel doing duty as tender till the steamer was ready, nor the cargo vessel bearing stores could stay with safety at Hynish, but had to shelter at Tobermory in Mull, or at Loch Erin in the island of Coll.

Everything landed on the rock during the first operations had to be fastened securely to ring-bolts fixed in the hard gneiss by the masons and smiths, so terrific was the force of the waves, and so little was the surface of the rock raised above the level of the ocean. Moving the heavy materials about the slippery rock was intensely tiring and exceedingly dangerous; yet the workmen were always unwilling to embark in the little vessel tossing and plunging upon the angry waters.

Two days' work only had been done when a heavy storm arose in which the tender was all but wrecked in making Hynish Creek, and nothing more in the way of building could be attempted for several days.

The weather having again moderated, a beginning was made with the setting up of the logs, fifty feet long and thirteen hundredweights in weight, to form the pyramid upon which the temporary barrack was to be fixed. The raising of the logs into position occupied six days. Sometimes when, by means of shear-legs, crabs or winches, ropes and ring-bolts, a log had been got almost into position, it had to be lowered again and fastened to the ring-bolts, owing to the sudden onset of a storm, or the coming of night.

The engineer tells us that the working-party usually landed on the rock about four in the morning, and worked till eight, when beef and bags of biscuit and jugs of tea were brought from the *Pharos* for breakfast. Half an hour later work was resumed, and continued till two o'clock, when vegetable soup, beef, biscuits, and beer were provided for dinner. This occupied another half-hour, and afterwards the work was continued until dark. The whole party then getting into the boats went aboard the tender, where supper was ready.

The setting up of the pyramidal framework had barely been completed, when so violent a storm broke out of the east that the tender was obliged to run for shelter to the Sound of Mull, and nothing more could be done on the rock till the 30th of August. Even then little could be effected. Heavy rain and a rising sea compelled the workmen at mid-day on the 31st to seek shelter at Hynish.

On the 4th of September, another landing being made, some useful work was done; and then the storm drove the toilers to Mull. On the 11th they finished and painted the pyramid of logs, lashing to the top a box of biscuit and a cask of water for the comfort of any poor seamen who might be wrecked on the reef during the winter months.

Operations were now over for the season; for, not only was the weather becoming dangerously broken and stormy, but the engineer wished to test the stability of the framework upon which the lives of himself and the workmen would depend.

It turned out, unfortunately, that he had altogether underestimated the force of the sea, for, in a terrible storm on the night of the 3rd of November, the whole structure was swept to destruction, the ironwork being completely shattered, and the heavy timber smashed and carried away.

The works at Hynish were, however, making satisfactory progress. It was found advisable to continue the building of the pier and of the various workshops during the winter; so that, though most of the workmen were sent home until the spring, three masons, nine quarrymen and a smith stayed on to quarry and dress the big blocks of gneiss which were intended for the lower courses of the tower.

Only about one-tenth quarried was found suitable for use in the building of the lighthouse; and this led Mr. Stevenson to examine carefully the rocks in the neighbouring islands and on the mainland. Finding the granite of Mull by far the most suitable for his purpose, he established, with the consent of the Duke of Argyll, a gang of quarrymen at North Bay, whence the blocks were sent to Hynish to be dressed and shaped.

So satisfactory was the quality of the granite, and so readily did it yield to the efforts of the quarrymen that, in little over a year, from April 1839 to June 1840, four thousand three hundred blocks, weighing from three-quarters of a ton to two and a half tons each, were shipped to Hynish, twenty-six miles away. Here they were carefully dressed and shaped so that each, when taken to Skerryvore, would fit accurately into its place. Dressing one of the largest of these blocks took a skilled mason eighty-five working hours, though some for the higher courses took one hundred and twenty hours. Others were made ready in a much shorter time; but the centre stone of each floor, into which all the other stones of the floor were dovetailed, required three hundred and twenty hours to dress.

The work of the summer of 1839 was the cutting out of the foundation. This was commenced early in May, and finished in September. The hardness of the rock, the unevenness of its surface, and the cramped space in which the men had to work, together with the care needed not to shake or split the rock more than was absolutely unavoidable, made the task tedious and slow.

The blasting was a source of great danger, it being impossible for the men to move off to a safe distance when the "shot" was fired. The danger was lessened by placing heavy mats over the mine, so that the fragments of stone were not able to fly into the air.

In this way, amid constant danger from the nature of the work and from the wild sea around the reef, a level foundation was gradually prepared, forty-two feet in diameter, upon firm and solid rock not undermined by the sea. A foundation pit, fifteen inches in depth, had now to be excavated; but only about one-third of this was finished at the end of the season.

A second wooden pyramid had, in the meantime, been set up. This was very much stronger than the first, consisting of thirteen fifty-foot logs bound and clamped together with ties of iron. Upon it the barrack was firmly secured, the whole being completed by the 3rd of September.

A landing-place was also blasted out, and a fifty-yards railway for the conveyance of blocks from it to the tower marked out for use during the next season.

The difficulties were increased by the mutinous conduct of some of the seamen on board the tender. These men, either fearing the danger of lying close to Skerryvore in the night-time, or wishing to force an increase of wages from their employers, frequently threatened to leave the vessel. So troublesome did the conduct of some become that the ship-master discharged them, hiring island boatmen in their place.

Even during the summer months the seas ran high round the reef; so that it was often exceedingly risky to attempt to land on Skerryvore. The boats were frequently half-filled with water, and on one occasion the men were thrown out, happily upon the rock itself.

When Mr. Stevenson resumed his labours in the spring of 1840, he was much gratified to find that the barrack had safely weathered the storms of the winter, though much of its paint was gone, and the sea-water had forced its way in through some of the joints. Even during the summer, while the men were living in the barrack, the heavier waves frequently flooded one or other of the rooms, while it was almost impossible to keep out the rain altogether. During the prevalence of a north wind the men had much ado to keep themselves warm; and, during the early part of June, when a terrible storm raged for nearly a fortnight, so that it was impossible for them either to get back to Hynish, or even to descend to the rock, they spent most of their time in bed, shivering miserably under the bed-clothes, and getting up only for their meals.

So impassable was the sea that the steamer dared not come near, though when at last she did venture, only twenty-four hours' provisions were left in the barrack.

When operations were at last possible, they were pushed forward with great energy. The men were called at half-past three, and worked till eight or nine at night, with only half an hour for breakfast and half an hour for dinner.

In spite of all difficulties, however, the preparation for the foundation made such progress that it was decided to lay the foundation-stone on the 7th of July. The ceremony was performed by the Duke of Argyll, who, with the Duchess of Argyll, the Marquis of Lorne, and a party of ladies and gentlemen, landed on Skerryvore.

Now that the real building had been begun, the value of the steady labours of the quarrymen and masons in Tyree and Mull began to show itself. The blocks, which were lifted from the decks of the four lighters built specially to carry them, were found to fit so exactly into their places, and to dovetail so perfectly into each other, that very little cutting or trimming was necessary.

Landing the stones was, however, a most dangerous task. The men on the lighters had often to be lashed to the rail to prevent their being washed overboard by the mighty seas; and more than once a lighter had to be towed back to Hynish with its blocks still on deck.

The season of 1840 was, nevertheless, exceedingly satisfactory. The tower was carried solidly up to a height of over eight feet, and because of its great diameter of forty-two feet, it was estimated by Mr. Stevenson that the mass of the blocks used was equal to nearly the whole of Smeaton's Eddystone Lighthouse, and to more than one-third of the famous Bell Rock Tower.

The season of 1841 saw another huge portion completed; and on the 25th of July, 1842, the last stone of the parapet was laid, and the steamer started for Greenock to fetch the lantern. Of the many hardships and dangers of those two seasons there is not room to speak; but it is satisfactory to know that during the whole building of the tower no life was lost, nor was there a single serious accident, though illness caused by the excessive exposure and strain was not uncommon.

Shear-legs and cranes, and crabs or winches were being taken down when Mr. Stevenson's father arrived at Skerryvore in the performance of his duties as engineer of the Northern Lights, to inspect and report upon the manner in which the operations had been carried out; and it must have been a happy moment for father and son, when they met at the base of the great tower raised by the genius of one which had been made effective by the careful training of the other.

The lantern—the chamber at the top which would enclose and protect the light—was finally fixed and glazed on the 14th of September, 1842, and the workmen departed. For another winter the tower would stand lonely, empty, and dark.

In January, 1843, Mr. Alan Stevenson was appointed engineer to the Lighthouse Board; but he continued to conduct the concluding operations at Skerryvore and Hynish. At Hynish the pier was now approaching completion, and a dock basin was being excavated.

The masonry of the Skerryvore Lighthouse is one hundred and thirty-eight feet and a few inches in height, as compared with the one hundred feet of the Bell Rock Tower, and the sixty-eight feet of Smeaton's Eddystone. The first twenty-six feet are solid, and a ladder of gun-metal, of that length, leads from the rock to the door. The interior consists of ten rooms one above the other, the uppermost being the lantern. The lowest room contains water-tanks holding over twelve hundred gallons; the next is filled with iron boxes of coals; the third is a workshop, while in the fourth are stored the provisions. The fifth room is the kitchen; the sixth and seventh are each divided by a partition and so form four bedrooms for the keepers. The eighth room is set aside for the use of the visiting officers who may happen to be storm-stayed, while in the ninth is kept the oil for the lamp which occupies the topmost storey or lightroom.

The light was first flung over the wild waters around Skerryvore on the 1st of February, 1844. It is a revolving light, giving its brightest flash once in every minute. Raised one hundred and fifty feet above the ocean, it can be seen from a great distance—sometimes from Barra Head, thirty-eight miles away.

The total cost of building the lighthouse and pier, and making the harbour at Hynish, together with the rest of the works at Hynish and in Mull, was over ninety thousand pounds.

The genius and skill needed to design and carry out such an enterprise, the patience, courage, and faith necessary not only to sustain the designer but to inspire the men who carried out his plans, in the face of such danger and hardship, entitle Mr. Alan Stevenson to a place amongst modern wonder-workers.

By an improvement on the method invented by Fresnel, a Frenchman, of greatly intensifying the light by means of reflectors and lenses, Mr. Stevenson added still further to his reputation. There is not space to go into the subject of lighthouse lanterns, or to explain how the rays from the central burner are collected by a wonderful system of mirrors, and then sent out in the desired direction by lenses specially ground and fitted; but it is by means of these reflectors and lenses fixed in a revolving frame that the differences in the duration and frequency of the flashes, by which mariners recognise the light, are produced.

After building Skerryvore Lighthouse, Stevenson built nine more; but no one of these

Skerryvore Lighthouse.

Erected by] [Alan Stevenson.

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approaches Skerryvore for mass, combined with beauty of outline.

Many honours were showered upon the young engineer. The University of Glasgow conferred upon him the degree of LL.D., and the Kings of Prussia and Holland and the Emperor of Russia each presented him with a gold medal.

Many people believe that great qualities of heart and mind are carried on from generation to generation ; and it may be that Alan Stevenson in some part owed his unflinching courage, and his steady determination to complete work once begun to his stern, unyielding Covenanting forefathers.

Another member of his family, Robert Louis Stevenson, the writer of *Treasure Island* and many other splendid books, showed the same invincible spirit, refusing to give up his work even when attacked by mortal illness, and remaining blithe and brave-hearted to the last.

But, just as Robert Louis Stevenson was physically worn out by the emotional strain of writing, so with Alan Stevenson the strenuous and incessant toil of his profession proved too great for his strength ; and in 1852 he was smitten with paralysis from which he never wholly recovered, dying in 1865 at the early age of fifty-eight. Of him it may be said with truth, that though he himself has passed away from earth, his work remains not only to cheer and warn and guide the toilers on the deep, but also to serve as an example and encouragement to those called upon to conquer difficulties and to perform arduous tasks.

III. Lord Armstrong.

ONE of the earliest things a baby boy does, when he has learnt to stagger around unsteadily without assistance, is to throw his toys about. Usually it is the kitten or the puppy at which he takes aim, after ineffective attempts to catch them. He realises that their pace is so much faster than his own, and their adroitness so far in advance of any of which he is possessed, that they can elude him with the greatest possible ease; and it occurs to him that, though he cannot overtake them, he can throw something that will.

What a baby does, half in play and half in earnest, the savage must do or die. The animals upon which he depends for food are too swift or too wary for him to lay hands upon them; but by means of a more or less effective missile he can stun or kill them, or disable them sufficiently to enable him to come up with them.

The most natural missile in countries where the rock crops through the soil is a stone; and many savages are most expert stonethrowers. But the strength of a man's arm cannot, after all, send a stone very far, or with much force; and many tribes quickly found a better way of propelling their missiles. A strip of soft hide, wide in the middle and tapering to the ends, was used as a sling; and, with this, stones could be propelled with force and accuracy.

David used a sling in his fight with Goliath, striking the giant while yet at a distance with so shrewd a blow as immediately to settle the combat in his favour.

The Roman legions of Cæsar's time contained slingers of such strength and skill that the stones slung by them were known to crush in breastplate or helmet. The best of these slingers came from the islands in the Mediterranean to the west of Spain. The name by which we know these islands—the Balearic Islands—means the "Islands of the Slingers."

The Australian natives never got beyond the throwing stage with regard to missiles; but they invented the wonderful boomerang, a throwing-stick so cleverly made that, propelled in the proper way, it will return to the thrower if he happens to miss the object of his aim.

The natives of South Africa—the Zulus and Kaffirs—became terribly expert in throwing the knobkerrie and the assegai. The knobkerrie was fashioned of hard wood, and consisted of a round head and a long handle or shaft; while assegais were broad-bladed spears of different kinds, some made specially for stabbing and others for hurling.

The throwing-spear, or javelin, was used in very early times. It is mentioned by various Greek and Latin writers, while frequent references to it occur in the Bible.

In North America the redskins had a habit of throwing tomahawks, or light axes, often with fatal effect; while the Sikhs of the Punjab, in India, flung sharp-edged war-quoits into the faces of their enemies.

For bringing down distant game, and for striking at an enemy at too great a distance to be attacked with sword or spear or even slung stone, another weapon was employed by nearly every primitive race, with the exception of the natives of Australia. This was the bow, by means of which arrows properly headed and feathered could be discharged with swiftness and deadly accuracy.

The Greeks considered the bow a cowardly weapon, though some of them were extremely skilful in its use. You will perhaps remember the story of the home-coming of Ulysses to the island of Ithaca after the Trojan War. Ulysses found many ambitious young men trying to win his beautiful wife, Penelope, believing, of course, that he was dead. Penelope, however, having resolved to be faithful to Ulysses whether he were dead or alive, had told the crowd of suitors that she would never think of marrying any man unless he could bend the great bow of Ulysses, and send an arrow through the rings set up in the hall.

Ulysses returned while the trials were going on, and for a time enjoyed Penelope's amusement at the efforts made by the young men to bend his bow; but at last he made himself known by sending an arrow whistling through the rings, to the joy of Penelope and the confusion of her suitors.

The Bible contains numerous references to bows and arrows, showing that their use was well understood by both the people of Israel and their enemies.

The long-bow used by English archers in old-time wars with the French and the Scots was as long as the bowman himself, and discharged an arrow a cloth-yard in length. Sir Walter Scott describes the English archer and his formidable weapon most delightfully in his splendid story, *Ivanhoe*.

The cross-bow was made of steel, and was placed upon a stock, which the archer held to his shoulder in a somewhat similar way to that in which a modern infantryman holds his rifle. The bolts or quarrels discharged from it were also made of steel, and at a short range could crash through the armour of the knight or footman against whom their flight was directed.

The defect in the cross-bow was that the string had to be drawn back by means of an apparatus something like the mechanism for winding up an old-fashioned clock. This made it really no match for the long-bow, from which a skilful archer could shoot a second arrow before the first had reached its mark.

It is a debatable point whether a body of English archers could not have defeated an equal body of men armed with the old flint-lock musket known as "Brown Bess." With this weapon British soldiers were armed until about the middle of last century; but when one considers the time it took to load, the bullet being wrapped in a bit of oily rag and pushed home with a ramrod, and the inaccuracy of its fire, it is easy to understand why officers and men trusted more to "cold steel"—the sword and the bayonet, the latter especially—than to their clumsy firearms. It was, nevertheless, the introduction of gunpowder into warfare which rendered the bow obsolete.

In besieging a strong fortress or city, the soldiers of ancient times often had a very hard task—it was so difficult to make a breach in the high, thick wall of stone. The longer but much easier way was to starve the inhabitants into surrendering.

Both besieged and besiegers used machines for hurling stones and darts—a primitive kind of artillery. Mention of machines of this kind is made in the Chronicles of the Kings of Israel, while the Romans, and probably the Greeks also, used the catapulta and the ballista, besides other machines for throwing missiles of various kinds. When Edward I. was besieging Stirling Castle he used such machines, some capable of flinging against the walls stones weighing over three hundred pounds.

Edward III. used cannon against the Scots, and also against the French at Creçy. These cannon, known as bombards, were formed of bars of iron strengthened by hoops. They were widest at the muzzle; and the balls discharged from them were usually made by the stone-masons who went into the campaign with the army for that purpose.

The gunpowder used in these early cannon was nearly the same as the black gunpowder of the present day. It was simply a mixture of saltpetre, charcoal, and sulphur, about seventy-six parts of saltpetre being mixed with fourteen parts of charcoal and ten of sulphur.

Gunpowder was used by the Chinese for charging rockets fully two hundred years before the birth of Christ; and in later years the Greeks made fireworks with it. Some people believe that the knowledge of the explosive was brought to western Europe by the Crusaders, who had heard of it from the Arabs; while others assert that it was discovered early in the fourteenth century by a German chemist. Be this as it may, by the middle of the fourteenth century guns were employed in naval battles and in fights ashore.

The early guns were constructed of copper or brass—after about the middle of the fifteenth century, that is to say—and many were beautifully decorated. They were of smaller size than those of the preceding century, and much more easily moved about, rough wheeled carriages being built to support them. The stone cannon-balls were abandoned in favour of cast-iron missiles.

The heavy cannon of the fourteenth and fifteenth centuries were chiefly employed in sieges to make breaches in the fortifications; but in the sixteenth century their value in regular battle was more widely recognised, and efforts were made to improve and lighten both gun and carriage.

It was not until the seventeenth century, however, that the artillery was regarded as a special division of the army. The famous Swedish warrior, Gustavus Adolphus, in his German campaigns, used four-pounder guns—guns, that is, which fired a shot weighing four pounds—drawn by two horses. He had before this time employed "leather guns," as they were called. These were light guns made of copper and strengthened with leather and rope! You will not need to be told that the charge of gunpowder must have been very small.

The usual way of charging these ancient weapons was to lift the powder into them by means of a ladle. When sufficient had been ladled in, a wad of leather, or some fibrous substance, was rammed home, and then the ball was pushed down until it touched the wad. A little powder was placed in the hollow surrounding the "touch-hole"; and the weapon being slung round and aimed, was fired by applying a light or a white-hot rod to the touch-hole.

The artillery used by royalists and parliamentarians during the civil war in the reign of Charles I. had little effect in deciding the issue of the conflict. Neither side possessed many guns or gunners, the cavalry doing most of the fighting. It was not, indeed, until 1716 that the Royal Artillery Regiment was formed by bringing together into two companies all the gunners in the army.

The English artillery, however, did some effective work in Marlborough's victories of Blenheim and Malplaquet, but it was not until Napoleon Bonaparte—who, by the way, had been an officer of artillery—had taken the matter in hand that the extreme importance of this branch of the military service was really recognised.

All the early guns were of smooth bore, except that some Prussian guns in the middle of the seventeenth century had shallow grooves running the whole length of the bore, to take up the foul residue caused by the burning of the powder. Rifled cannon such as we use nowadays were first made after the Crimean War. During this war a big smooth-bore naval gun weighing over three tons was brought from the British fleet to throw sixty-eight-pound shells into Sebastopol.

Guns were used at sea as early as the reign of Edward III. They were constructed at first of iron bars strongly hooped, and, like the guns employed in land-battles, fired cannon-balls of stone. The idea of piercing the bulwarks and sides of the vessel with port-holes occurred to some French ship-builders, who by this means rendered the guns of warships very formidable. This method of placing and firing the guns became usual during the reign of Henry VII., and the *Great Harry*, built by his son, Henry VIII., was armed with twenty-one heavy guns, and many of smaller size. The "royal" ships of the reign of James I. carried sixty-four guns of various kinds with wonderfully strange and fanciful names.

Nelson's ships were commonly armed with thirty-two-pounder guns, smooth-bored and muzzle-loading. Their effective range was a little over a mile; but at that distance they could not be depended upon to hit their object. Carronades were also used, throwing a heavier ball; but their range was even shorter than that of the cannon.

How long things might have remained in this stage is uncertain, had not the invention of rifled small-arms rendered smooth-bore cannon practically useless.

By "rifled small-arms" we mean firearms less than cannon—guns and pistols—having grooves running from end to end of the inside of the barrel. At first, as in the case of cannon, these grooves were quite straight; but it was afterwards found that if the rifling were given a spiral twist, the bullet flying from it would have a spinning or rotating motion which made it strike the mark with much greater accuracy.

Rifles were used in the British army about the date of the Crimean War; and in the battles of the Alma, Inkerman, and Balaclava, they helped the British soldiers to drive back the Russians.

So impressed was Napoleon III. with the superiority of rifled firearms that he had all his own bronze cannon rifled, using them afterwards with such effect in his Italian campaign against the Austrians that other nations, seeing they must be similarly armed, quickly abandoned or converted their smooth-bore artillery.

There was, however, one drawback to the use of rifled firearms. The projectile, however tightly it might fit the bore, left spaces through which the gas, generated by the burning of the powder, escaped. This not only reduced the force with which the projectile was propelled, but seriously damaged the rifle itself.

In order to overcome this disadvantage, the projectiles for big guns were fitted with studs which ran in the grooves, thus not only preventing the escape of gas, but helping to give the rotary motion to the projectile itself.

But it was found that these studs very quickly damaged the rifling, when few in number and working in deep grooves; while, if the grooves were shallow and the studs more in number, the case of the shell was seriously weakened.

Still, some years passed before a safer and better method was discovered.

Another improvement in both small-arms and cannon was introduced about the middle of last century. This was breech-loading instead of the old-fashioned muzzle-loading. The first nation to equip its entire army with breech-loaders was Prussia. The gun supplied to the Prussian soldiers was known as the "needle-gun," because, through the block closing the breech, ran the needle which struck the cap of fulminate—a highly explosive substance—and thus fired the cartridge, driving out the bullet.

So decisive was the advantage which the Prussians gained in the Danish War of 1864 by the use of the "needle-gun," that all the other European nations hastened to arm their forces with breech-loading rifles.

The British government, having quite recently rearmed its soldiers with the muzzle-loading Enfield rifle, was unwilling to go to the expense of discarding it and giving out an entirely new weapon. It was resolved, therefore, to adopt a method of converting muzzle-loaders into breech-loaders — a method invented by Jacob Snider, an American inventor then residing in England.

The first English breech-loading cannon was made by Mr. Armstrong—as he was then called

—shortly after the Crimean War. Mr. Armstrong's life-story is exceedingly interesting, as showing that the tide in the affairs of men that leads on to fortune comes frequently in an altogether unexpected way.

William George Armstrong was born in the year 1810 at Newcastle-on-Tyne, the busy northern city famed for centuries for its enormous export of coal, and for the beauty of the tower of its great church of St. Nicholas. His father, a native of Cumberland, was at the time of his son's birth a thriving Newcastle merchant, already keenly interested in the progress of the town of his adoption. He is gratefully remembered by the citizens of Newcastle as one of the founders of the Literary and Philosophical Institution of that city.

Young William was sent as a lad to the Newcastle Grammar School, there to receive that solid foundation of education without which the greatest genius is seriously handicapped in the race of life. It is said that, like young Brunel, he delighted in tools and machines at a very early age, thus, one would think, clearly showing to those responsible the career for which he was suited.

It may be that these early indications were not at the time so evident as they have since appeared, or that the boy himself did not rightly understand them. At any rate, a profession was chosen for him in which a knowledge of mechanics would hardly appear to be very useful. On leaving school he was articled to a local solicitor, in order that he might be trained to become a lawyer.

You will possibly think it strange, as you read of his later life, that he could ever have been a lawyer; and yet while he remained a member of that profession he worked diligently and faithfully. After serving the required number of years with Mr. Donkin, the lawyer to whom he was articled, he went up to London to complete his studies, and then, returning to Newcastle, became a partner in the firm of Donkin, Stable, and Armstrong, Mr. Donkin being his former employer.

For thirteen years Mr. Armstrong remained an active member of this firm, taking his share of all the different kinds of legal work entrusted to himself and his partners. You see, it is ever the way with the great ones of the earth to do faithfully the duty which lies nearest to their hands. Shirkers do not often rise to greatness, whatever may be their natural ability; for, when the opportunity at last arises for the exercise of their talent, they have grown too feeble and lazy to grasp it.

But the legal profession, arduous though its

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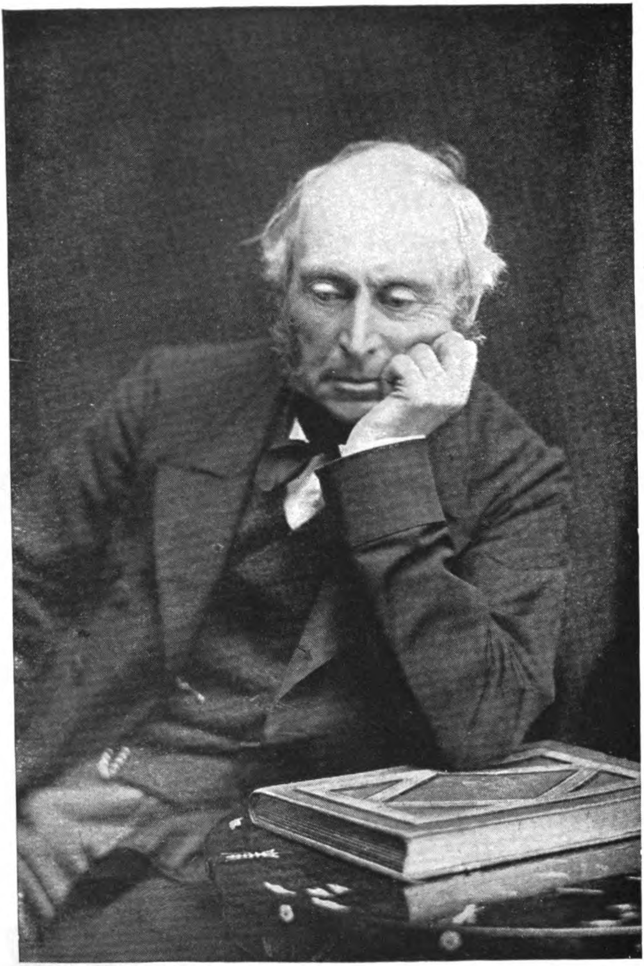

Photo.: W. & D. Downey.

P.P. Lord Armstrong. F

duties often are, does not usually take up every hour of the time of those who follow it; and Mr. Armstrong's mechanical tastes led him to spend his leisure in studying physical science.

Amongst other matters he was keenly interested in problems connected with water-power, or hydraulics; and his wide knowledge and inventive skill were placed freely at the disposal of the Newcastle Water Company in supplying the city with a service of water from Whittle Dene.

Continuing in the same line of inquiry, he invented the hydraulic crane in 1845, for which useful invention he was elected a Fellow of the Royal Society. This first crane was erected on the quay at Newcastle, and worked by water from Whittle Dene. The crane was used for loading and unloading ships, and proved to be of the greatest service. It was adopted by various port authorities, that of Liverpool amongst the rest.

A hydraulic accumulator, hydraulic machinery for hoists, for opening and closing dock-gates, turn-tables for locomotives, wagon-lifts, and capstans followed in rapid succession; and the former lawyer began to be recognised all over the country as a clever hydraulic engineer.

In 1847, in partnership with some other gentlemen, he started a small engine-works at

Elswick, then a place of no importance, but now a big suburb of Newcastle. The new venture did not at first promise to prosper; but, with the adoption of the hydraulic crane by the Liverpool port authorities, came a rapid rush of orders which, in a comparatively short time, made the works a paying concern.

Armstrong had now abandoned his legal business, and was applying all the powers of his mind to the solution of mechanical problems. Amongst other questions which interested him were those connected with electricity and with field artillery. The latter subject was brought prominently forward by an incident of the Crimean War.

It seemed to the western nations of Europe about sixty years ago, that Russia was likely to overpower Turkey and take possession of Constantinople. Neither France nor Britain was willing to allow this to happen; so, joining in alliance with the Turks, they declared war against Russia in 1854, and despatched a combined force to capture the fortress of Sebastopol in the Crimea. The Sardinians, who, under the able leadership of Cavour, had become the leading people of Italy, also sent a force to help the allies.

The fortress was at last captured, after a great expenditure of life on both sides, and a treaty was dictated by the victors: but the Russians had proved themselves stubborn foemen, and on more than one occasion had pressed the allies hard. One of these grimly contested battles was that of Inkerman. The Russians attacked early in the morning; and the British soldiers, called from their sleep to repel them, fought in the gray dawn with rifle and bayonet—even, it is reported, with stones and fists.

In spite of the bravery of the British, however, the day seemed doomed to go against them, for the odds were five to one; but, just at the critical moment, two eighteen-pounder guns were dragged into action. So well were these guns served, and so terrible was the havoc they wrought in the hostile ranks, that the Russians retired into Sebastopol. Had it been possible to bring these guns sooner into action, the issue of the battle would not so long have hung in the balance.

While most people looked upon the heaviness and clumsiness of the guns of the period as something that could not be helped, Mr. Armstrong endeavoured to think out a method of constructing artillery with an equal range, but much lighter and more easily handled.

With the small-grained gunpowder then in use —powder which really "exploded"—the strain upon the gun was so sudden and so enormous that, unless the cast-iron of which it was composed had great thickness and weight, there was serious risk of its bursting.

Mr. Armstrong's plan was to build up the gun from the inside. He saw there were two forces brought to bear upon the weapon when it was fired, one tending to tear it apart in the direction of its length, and the other to burst it. Now, iron and steel are about twice as strong in the direction of their fibre or grain as across it; and it occurred to Armstrong that an inner tube of steel, strengthened by outer coils of wrought-iron, would make a much stronger gun than the same weight of cast-iron; so that with less weight, and consequent greater ease in handling, field-guns might have quite as effective a range.

When he had worked out his theory he explained it to Mr. Rendel, one of the foremost engineers of the day; and so much was this gentleman impressed that he introduced the inventor to the Duke of Newcastle, then Minister of War. As a result of this introduction Armstrong was commissioned to build one gun upon his new principle.

The work was begun in the December of 1854, and finished in April, 1855; and in the following year the constructor had tested it sufficiently to submit it with confidence to the military authorities. To his disappointment the weapon was not very favourably received by the War Office: it looked so small and light that it was spoken of as a "pop-gun." So well, however, did it come through every test applied, that it was decided to commission Armstrong to make another and much heavier weapon on the same principle.

In making his gun, Armstrong so constructed his inner tube of steel that its fibres ran lengthways, thus giving their greatest resistance to the force tending to tear the tube apart. Over this tube thick coils of wrought-iron were shrunk, with their fibres running round or clasping the circumference of the gun, so as to give the greatest possible resistance to the bursting strain.

These coils of wrought-iron were forged, beaten out, that is to say, with heavy hammers, and the ends welded so that they formed iron rings of properly graduated circumference, and having shoulders by which they were to be held in position in the gun itself. The coil, ready welded and shaped, was now heated regularly and evenly till it expanded sufficiently to be slipped over the steel tube. As it cooled it shrank, gripping the tube firmly and with enormous force.

Another coil was now heated and slipped over the first, being sufficiently expanded to pass over the shoulders already mentioned. When it cooled, it settled securely into its place, adding still greater resisting strength to the inner tube.

So, coil by coil, the gun was built up, the resulting weapon being far in advance of any yet constructed.

It must not be supposed, however, that so vast an advance was made at the first trial. Various experiments were made, and iron and steel alike were tested, some of the earlier guns having inner tubes of wrought-iron.

Armstrong's patriotism was finely shown by his refusal to retain, for his own profit, the patents granted to him for his inventions and processes; for his country he had laboured, and to his country he freely presented the result of his toils. So highly valued was the work he had done for the nation that in 1859 he was knighted, made a Commander of the Bath, and appointed to the post of Engineer of Rifled Ordnance with a salary of two thousand pounds a year.

Armstrong's earliest guns were breech-loaders, the breech being closed with a block which was dropped into a slot and made tight by means of a screw pressing against it. This was not found to answer very well, the breech-block sometimes jumping out when the gun was discharged, and injuring the gunners. The men became almost afraid after a time to fire guns, which might as easily strike them as the target at which they were aimed.

During this period of experiment, wonderful discoveries had been made of methods of producing steel of fine quality in quantities greater than had been known before; and Sir Joseph Whitworth, of Manchester, invented a method of making cannon of cast-steel. So many people thought these guns superior to the Armstrong gun, that a commission was appointed by the government to test thoroughly weapons made upon the two systems, and to decide which was the better.

While this battle was proceeding, Sir William Armstrong resigned his post as Superintendent of the Royal Gun Factory for Rifled Ordnance. It is possible that the decision of the government to discontinue the use of the Armstrong gun, because of the dangerous breech-block, may have had something to do with his resignation. In the three or four years that he held the post, something like three thousand Armstrong guns had been introduced into the national service.

It is interesting to know that the first war in which British gunners used breech-loaders was the Chinese War of 1860.

The commission appointed to inquire into the merits of the Armstrong and the Whitworth guns decided in 1864 in favour of Armstrong's system, and the Government Ordnance Factory at Woolwich turned out some enormous cannon built up in that way, the "Woolwich Infant" weighing eighty tons.

Being now free to carry on his own business and his untiring experiments with guns and projectiles and gunpowder, Sir William was able within the next few years to astonish the whole world with the power of the cannon turned out at Elswick.

In 1878 the attention of every one connected with artillery was turned to the marvellous performance of the Armstrong six-inch gun, weighing less than four tons. From this weapon a sixty-four-pound shot could be fired at a speed of over two thousand feet per second—nearly twice the speed at which sound travels! At a distance of a quarter of a mile from the gun the shot would crash through eight inches of solid iron. If an eighty-pound shot were fired, it would pierce at the same distance a plate eleven inches in thickness!

Then followed another period of trials. A Woolwich-made gun of eighteen tons weight sent a shot through a nine-inch plate at a distance of five hundred yards, but could not send a shot through a plate twelve inches thick at a distance of ten yards. An Armstrong gun of only eleven and a half tons, on the other hand, sent a shot through the nine-inch armour-plate from a distance of three thousand yards, and one through the twelve-inch plate from a distance of two thousand yards.

A further test being made with a Woolwich 25-ton gun, it was found incapable, at a five hundred yards range, of driving a projectile through a fourteen-inch plate, a performance which the 11½-ton Armstrong accomplished with ease from a distance of two thousand yards.

How had this wonderful increase of power been brought about? Well, there were really three factors in Armstrong's success—an improvement in gunpowder, a change in the shape and length of the bore of the gun, and a most important change in the case of the projectile.

The improvement in gunpowder was a very remarkable and yet a very simple one. Powder in small grains exploded all at once, like gun-cotton, giving a sort of kick to the projectile, and testing severely the strength of the gun; while powder in large cubes or prisms burnt slowly in comparison, giving off gas which rapidly increased in pressure, pushing the projectile along the barrel of the gun with swiftly increasing force, and despatching it with vastly greater velocity than would be given by the explosion of small-grained powder.

In order to use up the very last ounce of energy, Sir William lengthened considerably the bore of the gun, taking care, however, that the length should be just sufficient to enable the gas generated by the burning of the powder to reach its greatest pressure at the moment when the projectile left the gun.

In order to increase the possible charge of gunpowder, the Armstrong gun was constructed with a "chamber," a wider portion of the bore behind the projectile; and it was the increased length of the gun needed to give the best result from this greater charge that made muzzle-loading guns unsuitable for warships.

One advantage of the breech-loader was that the projectile could be made slightly larger than the bore of the gun, with an outer coating or rings of soft copper. This slightly greater circumference held the shot firmly till the pressure of the gas behind it was equal to about two tons to the square inch. Then the softer metal yielded, and the shot began to travel down the bore, the copper coating or rings being cut by the steel rifling. The effect of this was two-fold—the copper "driving-band," as it was called, acted as a most effective gas-check by exactly filling all the grooves, while to the projectile was given that spin or rotation which rendered the range of the gun greater and its fire more accurate.

But you will naturally wish to learn if the weapons were safer to use than the first breech-loaders, which had been discarded. Sir William, tackling this problem with his usual energy, soon discontinued the use of the wedge-like breech-block, employing instead a breech-block resting in a frame hinged to the rear end of the gun, and so arranged that, after being pushed in, it could be made perfectly secure by a quarter turn.

While the British authorities were still wavering, an event occurred which helped to bring them to a decision. This was the bombardment of Alexandria in 1882. Arabi Pasha had rebelled against the Khedive of Egypt, and, winning the army to his side, had seized the country. The British, having many interests at stake in Egypt, decided to support the Khedive, and despatched a fleet and army to overthrow Arabi. The war was opened by the bombardment of Alexandria by British warships.

The cannon used were principally muzzle-loaders built at Woolwich upon the Armstrong plan. Their projectiles for the most part were fitted with studs to take the rifling; and during the bombardment two of these big guns, each eighteen tons in weight, were split, and others more or less damaged.

This series of mishaps finally decided the naval authorities, and the whole fleet was re-armed with breech-loaders constructed according to Armstrong's latest method.

Another ingenious way of building up a gun was afterwards put into practice at Elswick. The whole breech end of the gun was wrapped with layers of flat steel wire or ribbon, put on at a tension so enormous that the bore of the stout inner tube was actually decreased by the pressure, a jacket of steel being shrunk round the wire. With these "wire" guns astonishing results have been obtained.

In 1887 Sir William was created Baron Armstrong in recognition of his services to the nation. The works at Elswick continued to grow, employing more and more men, and soon there was added to the ordnance department a yard for the building of warships. From this yard some remarkably fine battleships, including several for Japan, have been launched.

Some years later another yard was taken at Walker-on-Tyne for the building of merchant-ships; and in 1897 an amalgamation with the old rival firm of Sir Joseph Whitworth and

Company added the works at Manchester to the business. A branch was established at Scotswood, about two miles higher up the river than Elswick, and another at Pozzuoli in Italy; so that the firm of Armstrong, Whitworth and Company has become one of the most extensive manufacturing enterprises in the world.

It is pleasant to know that, with all this wonderful success, Lord Armstrong ever remained the kindly, generous, warm-hearted gentleman who, from the first, won the hearts of his workmen by his careful consideration of their interests. When he received the honour of knighthood, they presented him with an address in which were the following words:—

"We, who have occasionally been permitted to witness your indomitable perseverance in pursuing your experiments under the most perplexing circumstances, with the most extraordinary zeal and energy, and have observed how frequently your disappointments and failures have been made the key to the successful attainment of your purpose, have become involuntarily interested in your most triumphant success, and do most sincerely rejoice."

To every good object and charitable organisation connected with his native city he was a generous subscriber, crowning his benefactions with the gift of the beautiful Armstrong and

Jesmond Parks. The lovely grounds around his country house, "Cragside," near Rothbury, were a source of delight to thousands of his fellow-townsmen; and though, during his later years, he withdrew very largely from public life, he remained to the last keenly interested in everything connected with Newcastle.

He died in the year 1900 at the advanced age of fourscore and ten, leaving behind him the memory of one who had, by his genius, unwearying patience, and business acumen, his kind heart and unstinted generosity, done much to increase the prosperity of his native town and to brighten the lives of its people.

IV. Lord Lister.

ONE of the noblest of all the callings to which men devote their lives is that of the surgeon. Upon his skill, his courage, his self-control and presence of mind, his steadiness of hand and keenness of eye, his scrupulous care and forethought, depends, in countless cases, the life of the sufferer to whose aid he has been summoned. There is no other profession which demands study so close and exact, training so thorough and arduous, together with so great an amount of self-denial.

The practice of such a profession draws out all that is best and highest in a man—sympathy with suffering, pity for the helpless, the will to give relief. The story of every war contains thrilling chapters bright with the deeds of the men whose mission it was to bind the wounds of the fallen, whether friend or foe—to snatch from the grim god of war some of his bleeding victims.

But it is not only amid the tumult and carnage of the battlefield that surgeons have risked and even lost their own lives to save the life of a patient ; many touching stories have been told of the quiet courage of the men who, in some great disaster, have moved about among the sufferers like angels of mercy, braving all dangers in the cause of humanity.

From the earliest times such men have been held in high honour ; and in some countries their calling has been regarded as almost, if not quite, sacred. This was especially the case in India, where the physicians and surgeons belonged to the priestly caste. Good surgeons these Hindus seem to have been. Their instruments, of which there were more than a hundred, were made of steel, perfectly clean and polished, and kept with an edge keen enough to divide a hair. These early surgeons had invented an excellent splint for broken limbs. It was composed of thin strips of bamboo tied together and cut to the length wanted. A similar splint is at the present time in use in our army.

The Chinese were not such clever surgeons as the Hindus ; but the ancient Egyptians evidently possessed no little skill in surgical cases, for we find on the walls of their temples pictures showing surgeons at work. Egyptian surgeons very early obtained a reputation for skill in operations upon the eye. They under-

Photo.: Elliott & Fry.

P.P.

Lord Lister.

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stood, too, something of dentistry; for mummies have been found with false teeth firmly set in their mouths.

Coming to rather later times — though still considerably more than two thousand years ago — we find the Greeks with a wonderful knowledge of the treatment needed for broken bones and dislocated joints. They could even perform that most dangerous and delicate operation called trephining, by means of which the brain may be relieved of pressure when the skull has been injured.

Strangely enough, Greek surgeons knew very little about the human body—there were amongst them no anatomists or physiologists. But the surgical school of Alexandria, which flourished two or three centuries before the birth of Christ, was famous for the study of anatomy—the build of the framework of the body. These Alexandrian surgeons were credited, too, with great skill in bandaging.

The Romans brought the surgical treatment of various diseases to a high point of excellence, using the knife with a boldness and skill hardly surpassed until recent times.

Some strange things were done by surgeons during the Middle Ages. It was usual for a "leech," as he was called, to attempt to lower the fever caused by wounds by opening a vein and drawing more blood from the sufferer. Gunshot wounds were treated with boiling oil!

In the sixteenth century surgeons began again to show the ability which had distinguished those of Egypt, Greece, and Rome. They began to devote long years to the study of the human body, the true key to surgical skill. The long, terrible wars of the succeeding centuries called for the almost constant practice of their vocation, causing a steady increase in the ability of the operator and in the suitability of his instruments.

The first really great English surgeon was Richard Wiseman, who acted in that capacity to James I., Charles I., Charles II., and James II. He wrote a book, which was for many years the standard work, upon the surgical treatment of wounds and diseases.

The barber-surgeon remained, however, a feature in most towns, not only in England but also in continental countries. His ghastly sign, representing a bleeding limb with a bandage wrapped round it, projecting from the door of his shop, acted as a guide to those in need of his services. The barber's pole of to-day is simply this ancient sign. How many deaths were due to the ignorant "blood-letting" and "cupping" of these people will never be known ; but the total must have been very considerable.

In the eighteenth century surgery became one of the recognised professions, attracting to its practice men of intellect and good family. Hunter in London and Monro in Edinburgh founded schools of surgery ; and surgeons began to take rank with physicians, and to be regarded as gentlemen.

In many other countries, however, they were not yet so regarded. In Germany, the regimental surgeons, even in the eighteenth century, were expected to shave the officers!

During the course of the nineteenth century surgery became more exact, and surgeons more skilful. Wonderful operations were performed, and most delicate and ingenious instruments invented. The list of the names of famous surgeons and teachers of surgery of the last century is a very long one.

Two names stand out beyond all others—those of Sir James Young Simpson and Lord Lister, the former because of his discovery that the breathing of the vapour of chloroform renders a patient insensible for a time to the most acute pain, and the latter for his introduction of the antiseptic treatment of wounds.

How awful must have been the agony of soldiers and sailors whose shot-shattered limbs were operated upon while the sufferers retained full consciousness! How much more difficult must have been the work of the surgeon under such conditions! To Sir James Simpson humanity owes a deep debt of gratitude.

To understand the importance of the antiseptic treatment of wounds introduced by Lord Lister, it is necessary to know something of what is called the "germ" theory of infection.

Those who have read the article on the work of Pasteur, given in another volume of this series, will remember how he proved that floating in the air are the germs of dangerous diseases, among them the germs of blood-poisoning, lock-jaw, erysipelas, and other dreadful disorders which find their entrance to the body through the breaking of the skin.

"A pin-prick is a door open to death," said a famous French surgeon. It is no wonder that, under such circumstances, surgeons often hesitated when an operation became necessary. It sometimes seemed as though it were but the choice between two evils which was given them —the patient might die of his disease, or he might die of blood-poisoning after the operation. The simple lancing of a gathering was known to be sometimes fatal.

The pity of it was that Simpson's discovery of the power of chloroform had made possible operations which, before, had been all but impossible because of the terrible pain and shock suffered by the patient. Chloroform put the sufferer into a deep sleep from which he woke after the operation had been performed, mercifully unconscious of all that had happened.

Then, to the anguish and despair of the surgeon, when the source of the trouble had been skilfully removed, and nothing remained but the healing of the simple wound, gangrene or erysipelas or some similar disease would make its appearance and carry off the patient.

The number of deaths after operations was appalling—a much greater proportion than had been the case centuries before. Surgeons could not account for it. They tried in various ways to overcome the evil—but not having the root idea of infection from outside, their efforts were of little avail.

The truth was that, while they had improved in surgical skill, and had increased their knowledge of the human body and its diseases, they had discarded just the very things which had rendered the surgery of olden times comparatively safe.

The boiling oil, the hot iron, and hot brandy or wine, which in the preceding centuries were commonly applied to the wound, were destroyers of disease germs, enemies of poisonous spores, or, to use the name now given to such applications, *antiseptics.*

The surgeons of the earlier half of the nineteenth century, however, were of opinion that such applications increased the inflammation of the wound, and used instead such things as poultices, ointments, and thick pads of washed linen — sometimes the remains of old hospital sheets! In such dressings the disease germs lived and throve vigorously; but the surgeons, believing the cause of the trouble to be within the body of the patient and not without, continued to use the dressings with fatal result.

During the siege of Paris by the German army in 1870-71, the French made numerous sorties from the city; and the number of wounded men brought back into the French lines was considerable. Devoted surgeons did all that their skill could accomplish and all that their wide experience could suggest, yet the number who recovered from their injuries was lamentably small.

The fetid smell of the wards where the poor sufferers lay groaning in anguish was almost unendurable — a smell caused by the horrible condition of wounds which, in a modern hospital, with modern treatment, would heal perfectly in a few weeks.

So little hope had the surgeons themselves of a favourable issue that one of the most skilful is reported to have said: "When an amputation (the removal of a limb) seems necessary, think ten times about it, for too often, when we decide upon an operation, we sign the patient's death-warrant."

Another French surgeon, filled with despair as he saw one fine stalwart fellow after another snatched from his hands by the same grim enemy, declared that he who should conquer this fell disease would deserve a golden statue. It moves one profoundly to reflect that, at this very time, across the Channel the great fight had already been won, and that the victorious plan of campaign had been suggested to the conqueror by the discoveries of a Frenchman—Louis Pasteur.

In other words, a method of dealing with wounds, which recognised the vital importance of preserving them from infection by the germs of disease, had been put into practice by an English surgeon, Joseph Lister, to whose mind the discovery had suggested itself after careful consideration of Pasteur's researches.

It is a most interesting fact, tending to show that the minds of these two investigators were of the same order, that Lister made free use of the microscope in examining into the causes of disease, as did Pasteur on the other side of the Channel. Lister's father, indeed, is remembered by the improvements in lenses by which he wonderfully increased the usefulness of the microscope.

Joseph Lister, afterwards to become one of the most famous of the world's surgeons, was born at Upton, in Essex, on April 5, 1827. His early education was obtained at the Quaker schools of Hitchin and Tottenham; and as he afterwards became a student at University College, London, taking his B.A. degree in 1847, and becoming Bachelor of Medicine and Fellow of the Royal College of Surgeons in 1852, Londoners proudly and justly regard him as one of their very own.

He was appointed house-surgeon at University College Hospital; and, while occupying that position, made a careful study of gangrene, one of the diseases which attack open wounds, causing the death of the tissues, and usually spreading rapidly with fatal result. He also studied most minutely the disease of pyæmia, a disorder brought about by the matter or pus of the wound being absorbed into the blood. This disease also was terribly fatal.

In examining into the causes of these two scourges, Lister used the microscope; and though he did not arrive at a solution of the problem, he convinced himself that the origin of the disease was rather in the wound itself than in the body of the patient.

So high was the mortality caused by these diseases after operations that people began to dread the name of hospital, and to speak of surgeons as butchers. Surgeons were in despair, and ready to try any means to combat the enemy who appeared to laugh at all their efforts. Thinking the walls of the old hospitals capable of poisoning the air of the wards, they had in some cases new hospitals built, carefully ventilated, and made as clean as soap and scrubbing could make them. This often had a good effect, at any rate for a time; but the death-rate continued to be appalling.

Lister was appointed to the chair of surgery in Glasgow University in 1860 — when thirty-three years of age. Before obtaining this appointment, he had won distinction in Edinburgh as a lecturer upon surgical subjects, and as a writer of learned papers, giving to the medical world the results of his untiring researches.

In Edinburgh, he was for some time house-surgeon to Mr. Syme, who was famous for his skill in operating, and who used a dressing of dry lint instead of the wet dressing used for wounds by the large majority of English surgeons. This better method caused some slight lowering of the death-rate; but the real enemy remained undiscovered.

It was thought by many that the air itself was the cause—not anything which might be in the air, but the oxygen, its active principle. People tried by every means to exclude the air from the wound, using for this purpose strips of sticking-plaster, and other dressings through which air would have difficulty in passing.

When Lister was appointed to the chair of surgery at Glasgow University, he was greatly concerned at the serious state of things prevailing at the hospital in that city. Death seemed to hold high carnival there; case after case ended fatally, in spite of open windows and the most unremitting attention.

People began to ask why hospitals were allowed to exist; even so great a surgeon as James Simpson openly asked if it would not be better to do away with the whole system. We can form, perhaps, some faint idea nowadays of the loss this would have been to the world; and we must not forget that the saving of the hospitals was due chiefly to Lister, who was at last able to show that the hospitals were not to blame for the infection of the wounds, but the instruments, the hands, the dressings of the operator.

After reading of the experiments of Pasteur, the thought came to Lister that the germs of which the French chemist spoke were possibly responsible for the mischief, the cause of which no one had as yet fathomed.

Feeling certain that he was on the verge of a supreme discovery, Lister resolved to employ a method entirely new. "If," he reasoned, "these 'germs' are the source of infection, the correct treatment will be to destroy them, not only in the wound itself, but also in the air surrounding the wound."

The best substance to employ, he thought, would be carbolic acid. This he knew to be effective in taking away bad smells, so he concluded that it might be a "germicide" or germ-killer.

The most fatal of all the cases were those of compound fracture, where a portion of the broken bone sticks out through the flesh. Under the old system most of these cases ended fatally, while those of simple fracture, where there was no breaking of the flesh, generally ended favourably. This fact amongst others led some surgeons to believe that the air itself was responsible for the poisoning of the wounds.

Lister, however, became convinced that, though the air might possibly convey the disease-germs to the wound, it was not itself the cause of the disease. Thinking over Pasteur's discoveries, he came to believe that the blood in the wound was caused to decompose by germs from without;

that this decomposition was the source of all the troubles that followed; and that if these germs could be kept from entering the wound, no poisoning would take place.

Lister resolved to experiment first upon cases of compound fracture, in which the percentage of fatalities was so high. He covered the wounds with carbolic acid or phenol, a liquid obtained in large quantities from coal-tar; and the caustic or burning properties of the acid caused the blood to form into a thick crust entirely covering the wound. To keep this crust free from infection, it was painted every day with the acid. The results obtained from this treatment were most gratifying—case after case ended in perfect recovery.

This method of dressing wounds was termed the antiseptic treatment, from *anti* (against) and *sepsis* (putrefaction).

The system, however, had one serious defect—the carbolic acid acting upon the patient's flesh caused severe pain, and it was felt necessary to obtain some substance which, while not interfering with the action of the acid in keeping the wound healthy, should lessen its severity. Experiments undertaken for the purpose of finding the perfect medium—the substance with which the acid should be mixed—were continued over several years.

One medium which Lister employed with success was ordinary putty — whiting mixed with boiled linseed-oil, crystals of carbolic acid having been dissolved in the oil. The wound was covered with this antiseptic putty, which was changed daily, the result being highly satisfactory.

There seemed, however, to be one serious objection to this method of treating wounds. When so serious an operation had to be performed as the amputation of a limb, the arteries which had been severed were tied to prevent the patient's bleeding to death. These ligatures, as they were called, were of silk; and before the wound could be allowed to close they had to be thrown out or "separated." This was done by the gathering or suppuration of the wound; and some surgeons argued that Lister's method, which prevented suppuration, was unsuitable for such cases.

Lister attacked this problem in his usual careful and patient way. He believed that the ligature itself was often the cause of the suppuration, and he thought if it were made aseptic —incapable of causing putrefaction—by being steeped in carbolic acid, it might quite safely be left in the wound. Afterwards, however, he came to the conclusion that a ligature of silk left buried, so to speak, in the body, might not be altogether harmless. He resolved, therefore, to use catgut for this purpose, since that was of an entirely animal composition, and might be absorbed.

The result was astonishing; not only was the catgut perfectly absorbed, but tissue took its place as a ligature, thus keeping quite safe the tied artery. This discovery alone would have placed Lister in the foremost rank of the surgeons of all time; and yet it would have been impossible to use catgut for this purpose had it not first been rendered aseptic by steeping it for some hours in carbolic acid.

The best dressing to be used also became the subject of much thought and experiment. The putty was excellent in many ways, but it was clumsy and easily broken; while the fact that it had to be made fresh for each dressing was an additional difficulty.

After trying various substances, Lister decided that muslin of an open texture, saturated with a mixture of resin, paraffin, and carbolic acid, was the best means of applying the antiseptic treatment to wounds and sores.

In the year 1869 Lister was appointed to the chair of surgery at Edinburgh University, rendered vacant by the death of his father-in-law, Mr. Syme, with whom, it will be remembered, he had for some years been house-surgeon.

About this time, or shortly afterwards, he began to use what was known as an antiseptic spray. Carbolic acid, much diluted with water, was driven from an ingenious instrument in the finest possible spray into the air around the wound while the surgeon was operating, or while he was changing the dressings.

By this means Lister tried to ensure that no germs floating in the air should come near the wound; and, though afterwards convinced that the infection of the wound was due, not to the germs in the atmosphere but to those introduced by the tools or hands of the surgeon or by the dressings, many years passed before he dared to abandon the use of the spray, so wonderfully successful had been the treatment of cases where it was used.

Surgical work, lectures, and the writing of papers occupied much of the surgeon's time during his stay in Edinburgh. By constant research, experiment, and close reasoning, however, he improved step by step the treatment of wounds, obtaining results so marvellous as compared with those of only a few years before, that even those who had opposed his methods and denied their usefulness were obliged to acknowledge that no other methods could compare with them in safety and success.

On the Continent, especially in Germany, Lister's system found almost instant favour. So enthusiastic were the surgeons of Munich and Leipzig that, when in 1875 he visited those cities, public festivals were held in his honour.

In 1877 he was appointed to the chair of surgery at King's College, London, a position which he continued to hold till 1893. He believed that by living and working in London, he would be able, as it were, to keep his finger on the world's knowledge of surgery, and so the better help forward his efforts for the good of mankind.

It was felt that work such as he had done demanded public recognition, and in 1883 he was created a baronet. In the same year the surgeons of Budapest, the capital of Hungary, gave a banquet in his honour, the students afterwards marching in procession through the streets to the light of flaring torches.

Honour after honour was showered upon him. In 1895 he was elected President of the Royal Society, holding that position for five years; while in 1896 he was President of the British Association. In 1897, when seventy years of age, he was created Lord Lister of Lyme Regis, having thus gained a peerage by unremitting labour in the service of mankind. Later still, among the honours conferred on the occasion of the Coronation of King Edward was that of the new Order of Merit given to Lord Lister.

On his eightieth birthday, April 5, 1907, he received congratulations from medical societies, universities, and colleges; while the Royal College of Surgeons resolved to gather together and to publish in book form all his various papers.

One of the finest tributes paid to him was that of the poet William Henley, who for eighteen weary months was a patient in the Edinburgh Royal Infirmary. This is what he says:—

> His brow spreads large and placid, and his eye
> Is deep and bright, with steady looks that still,
> Soft lines of tranquil thought his face fulfil—
> His face at once benign and proud and shy.
> If envy scout, if ignorance deny
> His faultless patience, his unyielding will,
> Beautiful gentleness and splendid skill,
> Innumerable gratitudes reply.
> His wise, rare smile is sweet with certainties,
> And seems in all his patients to compel
> Such love and faith as failure cannot quell.
> We hold him for another Herakles,
> Battling with custom, prejudice, disease,
> As once the son of Zeus with Death and Hell.

It is interesting to know that Lister himself wrote to Pasteur, thanking him for what he had done in the service of mankind. It may not be out of place to quote a few lines from this letter—they show better perhaps than could anything else, the beautiful simplicity and lack of all unworthy conceit of one whose fame was in all men's mouths. The letter, sent from Edinburgh in February 1874, contained these words:

> Allow me to take this opportunity to tender you my most cordial thanks for having, by your brilliant researches, demonstrated to me the truth of the germ theory of putrefaction, and thus furnished me with the principle upon which alone the antiseptic system can be carried out. Should you at any time visit Edinburgh, it would, I believe, give you sincere gratification to see at our hospital how largely mankind is being benefited by your labours.
>
> I need hardly add that it would afford me the highest gratification to show you how greatly surgery is indebted to you.

These two great men met at the International Medical Congress held in London in 1881, supporting each other in the discussions which took place at the various meetings.

Lord Lister's experience led him gradually but surely to the conviction that the germs in the air might as a rule be disregarded in surgical cases, and that the antiseptic spray was not absolutely necessary; but he proved clearly that unless the hands and instruments of the operator and of his assistants, the skin of the patient, and all the dressings to be applied to the wound, are made aseptic—free from all germs—serious trouble will almost certainly result.

The amount of care and time spent by surgeons in rendering germ-free everything which may be used in attending to their patients is little guessed at by the unthinking public, though life and death depend upon the thoroughness with which this work is accomplished.

Some idea may be gained of the need of the most scrupulous care, when it is remembered that the most highly polished steel instrument, seen under a powerful microscope, shows many grooves and scratches on its surface. In these grooves whole colonies of germs can thrive and flourish in spite of the most vigorous polishing. In two ways only can they be destroyed—by heat or by an antiseptic such as carbolic acid.

With the experiments and researches by which Lord Lister and other surgeons and chemists have added to the list of antiseptics, and with the wonderful progress in surgical science which has taken place during the last forty years, there is not space to deal.

It is, however, no exaggeration to say that Lister's paper, entitled, "On a New Method of Treating Compound Fracture, Abcesses, etc.," which was printed in the *Lancet* of March 16, 1867, was the beginning of a new epoch in surgery. As a result of his discovery, the number of fatalities after surgical operations has decreased to a very small percentage indeed; and hospitals, instead of being hotbeds of infection to which patients went unwillingly and with small hope of recovery, have become one of the greatest blessings of our age. Their whole atmosphere has changed: instead of being the abodes of gloom and death, they are filled with the health-giving influences of cheerful confidence and well-founded hope.

Amongst the benefactors of mankind, to whom is due the gratitude of the human race, Lord Lister will ever take a very high place. It has been said that "Man's inhumanity to man makes countless thousands mourn;" but the splendid work of such men as this famous surgeon has made, and will make, countless thousands rejoice.

The world's conquerors have pursued their devastating course over the bodies of the victims whose lives have been sacrificed to their ambition; but along the track that Lord Lister has followed stand those whose lives have been saved through his patient and self-sacrificing labour.

V. Sir William Henry Perkin.

"MAUVE."

Many of you have doubtless spent a couple of happy hours at the pantomime, laughing at the jokes and comical sayings, wondering at the skill and lightness of the dancers and acrobats, and exclaiming at the beauty of the dresses and the scenery.

Perhaps what struck you most was the brightness and wealth of colour of the exhibition. Red and blue, orange and green, purple and yellow, are arranged by a clever artist, who blends the various tints so as to form a beautiful picture, while from the lime-light lanterns constantly-changing floods of vivid colour fall upon the performers.

Suppose yourselves asking some one who knew, where all these tints were obtained. You would possibly expect him to show you a sort of magic room, with windows of stained glass, filled with crystal beakers of coloured liquids. You would be quite disappointed and possibly unbelieving if he took you to a gas-works.

And yet, most of the lovely colours used in dyeing the dresses and scenery you so much admired at the pantomime, were obtained from coal-tar. Most of the dyes used sixty years ago were vegetable dyes, obtained, that is to say, from plants. Such were indigo, madder, willow, logwood, and walnut rinds, giving blue, red and purple, yellow, black or purple, and fawn colour.

Most of these dye-stuffs and many more from the vegetable kingdom are still in use, besides a large number of mineral dyes; but some of the most brilliant colours are obtained from coal-tar, though the method of preparing the dyes from that black substance was discovered only half a century ago.

The art of dyeing was known to many nations of the ancient world. The Egyptians, Greeks, and Romans all understood how to give rich colours to their fabrics; but perhaps the most famous of the ancient dyes was the purple of the Phœnicians, often called, from the name of their chief city, Tyrian purple.

This beautiful colour, so expensive that robes of Tyrian purple were worn only by kings and other royal persons, was prepared from a little shell-fish, generally found on the rocky coasts of the Eastern Mediterranean.

After the conquest and ruin of the beautiful city of Tyre by the conquering Turks, the dyeing industry fell, during the Middle Ages, into the hands of the Jews; and for about three centuries they kept up the art in Italy, their secrets gradually passing into the hands of the Italians, and chiefly of the Venetians.

Dyeing was little understood in England until recent times. Even so late as the beginning of the seventeenth century, the woollen fabrics, for which England was early famous, were sent across to Amsterdam to be dressed and dyed.

For many years after that the English dyers had no knowledge of the art. All they did was to scour the fabric, and then to dip it into a liquid coloured with vegetable juices. This kind of dyeing was very unsatisfactory, and the colours were seldom lasting.

In the middle of the eighteenth century some mineral dyes were discovered and employed. Thus, a preparation of iron gave buff, a preparation of copper gave green, another of antimony gave orange, and yet another of iron and potassium gave Prussian blue.

In the year 1821 chrome-yellow and chrome-orange were prepared from lead, and shortly afterwards a fine brown from manganese.

But it was not until 1856 that the first of the brilliant coal-tar colours was discovered by William Henry Perkin.

Before the story of its discovery is told, it will be well that you should understand what coal-tar is, and how it is procured.

Take a piece of coal and look at it carefully. You will find it hard, black, and shining, easily broken, and arranged in layers of greater or less thickness. If you were to ask a chemist of what it is made, he would reply that, except for a very small portion of mineral matter, it is made up of carbon, hydrogen, oxygen, nitrogen, and a very little sulphur.

Now, put the coal upon a bright fire, and watch it as it is consumed. Before very long tiny jets of smoky vapour escape from it, and, catching fire from the heat around, burn brightly, making a cheerful sound of hissing and sputtering as they do so.

When the flames have all died down, pick up the coal with the tongs and look at it. At first it is a glowing red, but, as its heat is given away to the surrounding air, the colour fades to a dull grayish black, and you find you are holding a spongy-looking mass of what you call cinder.

Now, take another piece of coal, and, instead of putting it on the fire, break it up into dust, put it into the bowl of a clay pipe, cover the bowl with clay, and thrust the pipe into the heart of the fire, taking care that the stem sticks well out.

In a few moments you will see a smoky vapour coming from the stem, and floating away up the chimney. Hold a lighted match to this vapour and it soon catches fire, burning brightly for some time. When the light goes out remove your pipe and let it cool, and then break open the clay cover. Inside the bowl you will find a mass of black cinder very like that you examined before.

The difference between the two experiments is that, in the first, the gases driven out of the coal by the heat of the fire were consumed as fast as they issued, while in the second they were conducted to some distance before being ignited.

The cinder left in each case is chiefly carbon, so that the vapour which has been consumed was composed of hydrogen, oxygen, nitrogen, a little sulphur, and the rest of the carbon not contained in the cinder.

These five elements, however, are by no means in their simple state. They are in combination one with another, forming substances composed sometimes of two, sometimes of three or more of them.

Many of these substances, or "bodies," are found in the form of vapour only when they are heated, and become liquid as soon as they cool. Some of the others give no part of the light when burnt, but in burning form poisonous compounds which it would not be safe for you to breathe.

Imagine now your pipe thousands of times bigger, and the stem of it leading away to a long, enclosed trough of water. Here many of the bodies would condense, the gas bubbling through the liquid, and escaping at the end.

This is roughly what takes place in the gas-works. A quantity of coal is put into a "retort," as it is called, and here it is heated, care being taken that no air can get in. The vapour given off is conducted by pipes to a long, horizontal cylinder half-filled with water. Here the coal-tar and some other bodies condense, and remain in the water, while the gas passes on to be further purified before entering the big gas-holder.

Let us now examine this coal-tar. At one time this, with the other by-products of coal-gas making, was considered a nuisance, the only trouble of the gas-makers being how to get rid of it most easily. Now, it is so valuable that, if gas were to cease to be employed to give light, the owners of gas-works would still go on treating coal in their retorts for the sake of the tar. You have probably all seen tar, and know that it is a thick, impure, slowly-flowing, dark-coloured substance, with a not unpleasant smell.

This tar is by no means the simple substance it might at first sight appear. It contains compounds of carbon and hydrogen, with one of which, benzol or benzene, you are perhaps familiar; but another, anthracene, so important that it must be mentioned, you are not likely to know.

It contains also compounds of carbon, hydrogen, and oxygen, different altogether from the compounds of carbon and hydrogen. One of these, phenol, you may hear of again.

Lastly, it contains compounds of carbon, hydrogen, and nitrogen, of which aniline is the one with which we shall have to deal.

You may ask how these various substances are separated from each other. The secret is a very simple one. Each has a different boiling-point; so that, if you put the tar into a retort, and heat it only to a certain temperature, only a certain body will turn into vapour and pass on into the condensing-chamber. As soon as it is all gone, the temperature may be raised to the boiling-point of the next body, and so on till all have been turned into vapour, condensed, and stored.

This is very seldom done at one time, the usual method being to turn into vapour and condense together all those bodies contained in the tar, which are lighter than water. The oily liquid into which they condense is known as coal naphtha.

Then the bodies heavier than water are turned into vapour and condensed. The liquid into which they condense is known as "dead oil." Left in the retort is liquid pitch, heavier still.

But, you will ask, what has all this to do with beautiful colours? That is exactly what Sir William Perkin discovered. Perhaps it will be better to tell you something of his life-story.

William Henry Perkin was the son of a London builder, and was born on March 12, 1838. His father wished him to become an architect; but the boy's tastes and talents did not lie in that direction. As a young boy he was interested in machines of any kind, and almost made up his mind to be an engineer.

When about twelve years old, however, he had the good fortune to see some interesting chemical experiments, and at once resolved that he would be a chemist—not a seller of drugs, but a student of the composition of various substances.

He was at this time a new scholar at the City of London School, and was much interested in the science work which was part of the school course. The study of science forms nowadays an important part of the work of most good schools, but, in the year 1850, the City of London School alone gave it a place in the ordinary school lessons.

The teacher of science was Mr. Thomas Hall, who had been a pupil of a very celebrated chemist, Professor Hofmann. He was very much in love with his subject, and made his scholars love it too.

When fourteen years of age, William Perkin obtained from Professor Michael Faraday a written permit to attend his lectures on electricity at the Royal Institute. This showed how eager he was to obtain any information within his grasp; but chemistry had always the greater charms for him. He was soon appointed laboratory-assistant to Mr. Hall at the City of London School, his principal duty being to prepare the materials needed in the experiments taken during the next lecture.

The only time during which the work could be done was the dinner-hour; and so keen was young Perkin over it that he often forgot all about his dinner till too late.

His father still wished him to become an architect, and it took all the powers of both William and his teacher to induce him to change his mind, and allow the lad to go, in his fifteenth year, as a scholar to the Royal College of Chemistry.

Here be became a pupil of the German chemist, Professor August Wilhelm Hofmann, a man who was not only a profound student, but one who had the power of making others as eager as himself.

Perkin proved so apt a pupil that before long Hofmann set him to examine, and experiment upon anthracene, one of the coal-tar products. You will remember that it is a compound of carbon and hydrogen. The chemists' name for these substances is "hydro-carbons."

In the formation of this special hydro-carbon, fourteen parts of carbon combine with ten parts of hydrogen. Young Perkin found this in the course of his experiments; but, as it did not agree with the formula accepted at that time, the experiments were given up, though they proved afterwards of great value.

At the Royal College of Chemistry there was a small laboratory, where promising students were allowed to carry out examination of various substances.

At the early age of seventeen Perkin was appointed an assistant in this laboratory, his duty being to see that each student was doing his work on correct lines, and that all were supplied with the material they required.

His duties were fairly heavy; and, in order to keep abreast of his own work, he persuaded his father to allow him to set up a little laboratory at home for evening work.

He was now very busy trying to produce the drug known as quinine. This is obtained from the bark of the cinchona, commonly called Peruvian bark. It is a compound of carbon, hydrogen, nitrogen, and oxygen.

A couple of years before, Hofmann had said it might perhaps be made by taking a substance compounded of carbon, hydrogen, and nitrogen, and making them combine with oxygen.

Proceeding on these lines, Perkin took a substance having these three elements in the same proportions in which they are found in quinine. This he caused to be acted upon by another substance containing oxygen, so that some of the oxygen combined with the first substance—but the result was not quinine.

Still, it was very interesting, and Perkin resolved to continue. He now thought he would try what effect oxygen would have upon other bodies containing only carbon, hydrogen, and nitrogen. There are several such substances found in coal-tar; and upon one of these, aniline, Perkin tried his first experiment.

Taking a small quantity of aniline, he mixed with it a little potassium bichromate, which readily parts with its oxygen. Pouring some dilute sulphuric acid upon the mixture he awaited the result.

After the usual bubbling and boiling, the solution gradually cleared, leaving a black sediment at the bottom. This he carefully collected and washed, afterwards dissolving it in spirits of wine, when he discovered the solution to be of a beautiful purple. Driving off the spirits of wine, he had left a powder or paste, two or three grains of which gave to a bucketful of water the most beautiful purple tint.

Young as he was, Perkin saw that he had discovered a new dye. Silk and woollen goods, dipped into the solution, became at once so deeply dyed that no amount of washing or bleaching would bring the colour out again; and the tint was so lovely that Perkin knew, if it were once placed upon the market at a reasonable price, the demand for it would be very great.

Seeing the value of his discovery, he lost no time in registering the process, thus preventing others from using it without his permission. In order to do this, he had to give the new colour a name, and chose that of "mauve," which the colour has been called ever since.

But there were still difficulties in the way of its becoming a profitable invention. Aniline,

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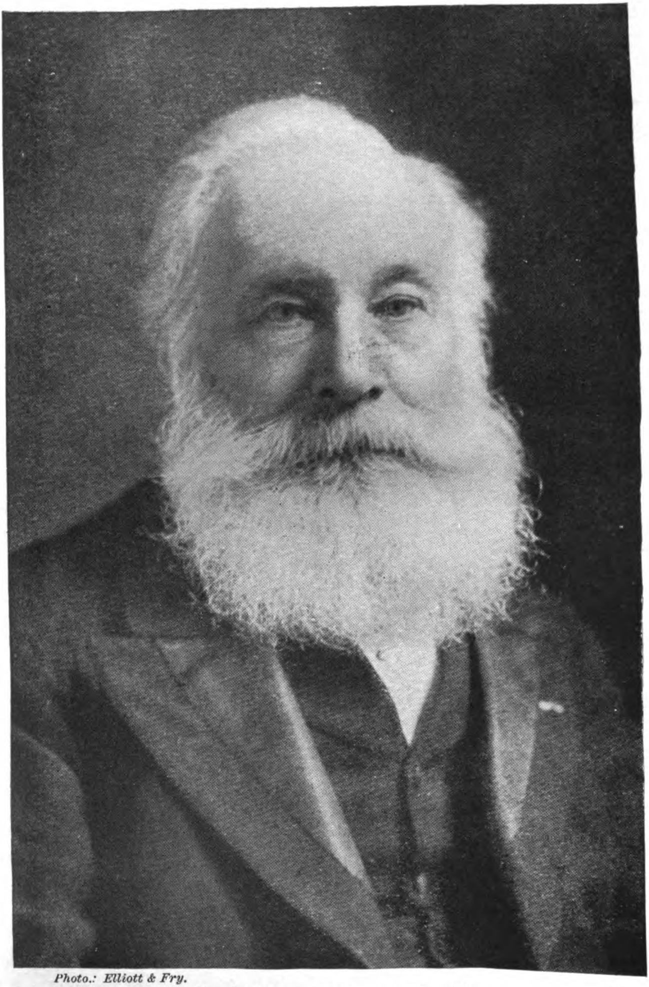

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P.P. Sir William Henry Perkin. 1

from which it was prepared, was very expensive. Only a small percentage of it was to be found in coal-tar, and any sudden demand for it would raise the price.

Pullars, the dyers, of Perth, to whom Perkin had sent some of his new dye, wrote to him a most encouraging letter; but his teacher, Hofmann, did not look upon the matter so favourably. He saw that Perkin was fitted by nature to be a famous chemist, and was afraid that, if he began the manufacture of "mauve" on a large scale, he would become so wrapped up in his new business that he would have no time for research.

Another thing which rather discouraged Perkin was that his dye, while acting powerfully upon silks and woollens, had little effect upon cotton fabrics. Now, the dyers of cotton and printers of calico are some of the biggest dye-consumers in the world; and a dye which was useless to them could hardly be a very profitable manufacture.

With the hopefulness of youth, however, the young chemist set himself to find some cheaper way of producing aniline on a large scale.

In 1825, Faraday had discovered the substance named benzol, by compressing gas prepared from oil. In 1845, Professor Hofmann discovered the same substance in coal-tar. It is, as has already been stated, one of the hydro-carbons. It is very inflammable, and its vapour, mixed with air, is explosive.

If this liquid be added in very small quantities to strong nitric acid, which has been warmed in readiness, there is a great deal of bubbling and boiling. If, when the action has ceased, water be added, there falls to the bottom of the vessel a thick, oily, yellow liquid. This is nitro-benzol.

This new substance is a very remarkable one. It has an agreeable smell and a pleasant taste, and is often used for scenting soap. Its manufacture, however, is dangerous, as it is very liable to explode during its formation.

The next step is to bring nitro-benzol into combination with hydrogen gas in the making. In these circumstances a chemical change takes place, during which the nitro-benzol and the hydrogen form aniline and water.

When acetic acid and iron filings are heated together, hydrogen gas is given off; so that if nitro-benzol, acetic acid, and iron filings are heated together, the result is aniline and water, plus the remains of the iron filings.

This was the process Perkin resolved to employ to make his aniline on a grand scale.

Aniline when quite pure has no colour, but has a rather pleasant scent. It is a liquid, oily-looking like nitro-benzol. It was discovered in 1826 by the chemist Unverdorben; but not from coal-tar. He was experimenting with indigo, and found that this new substance could be obtained from it. It is believed, however, that as early as 1750, a chemist named Hellot had discovered it.

Another German chemist, named Kunge, detected it in coal-tar in 1840, and Fritsche found it in another way; but it was left to an English lad to show how it might be made of such use, as a basis for dyes, that a large industry could be built up around it.

So promising did Perkin feel the prospects of this new industry to be that, in 1857, he persuaded his father and his brother to become partners with him; and a beginning was made with the building of the works at Greenford Green, near Harrow.

The difficulties in the way of the young firm were very great. Not one of the partners knew anything about chemical works; and the industry in which they were about to engage was so new that many of the instruments had to be made to their own designs. Before beginning to manufacture dye, they had first to make nitro-benzol, and then aniline.

So well did they work, however, that, before the end of the year, they were selling their purple dye to many of the silk-dyers.

The problem which young Perkin now set himself, was to find out some way of using his dye on cotton fabrics. His perseverance was rewarded by the discovery of a very satisfactory method, Pullar, of Perth, making the same discovery at the same time.

All difficulties were overcome, and, now that the dye could be used for printing calico and dyeing cotton, the demand for it increased.

Perkin's success set other chemists, both in England and on the continent, experimenting with aniline, in the hope of discovering another colour. Other bodies were used which gave up oxygen freely, and, in 1859, a French chemist named Verguin obtained a lovely colour which he named magenta, by treating aniline with chloride of tin.

Other chemists, Perkin himself amongst them, produced other colours.

But now the German chemists were hard at work in their untiring, patient way. In 1868, two of them, Graebe and Liebermann, discovered that from anthracene, one of the coal-tar hydrocarbons, could be obtained the beautiful substance "alizarin," the colouring principle of the vegetable dye, madder.

Their method was a very expensive one; but it set Perkin thinking. Anthracene was the hydro-carbon upon which he had made his first experiments ; and it struck him that alizarin might be formed much more cheaply by varying his experiment. He had set himself a hard task, but at last he succeeded, and alizarin, from which all the beautiful rose-colours and pinks and crimsons obtained from madder could be got much more cheaply, was turned out from the Greenford Green Works in increasing quantities.

From that date the works have had frequently to be enlarged. Dr. Perkin himself, after building up a huge business, retired from it in 1874, in order to devote his whole time to science. One of the industries we owe to him is that of the manufacture of scents, the method of producing which from phenol and other coal-tar products he discovered.

All kinds of honours were showered upon him, both in this country and on the continent, and the string of letters he could write after his name was amazing. He was knighted in 1906, a year before his death.

The business he built up at Greenford Green is no longer in existence—only a few big centres of chemical industry are left to us. Year by year, more and more of our trade in the manufacture of chemicals of all kinds passes into the hands of German firms; and, though we produce more coal-tar than any other country in the world, the manufacture of aniline, of alizarin, and of all the coal-tar colours is rapidly passing from us.

It may be useful to examine briefly some of the causes of this misfortune—for, when an industry for which our country seems specially fitted, and which would employ thousands of our people, passes to another nation, we can call it nothing but a misfortune.

First of all, how has this industry come into existence? By applying to actual manufacture new truths discovered in the laboratory. Here is one point upon which we, as a nation, are beaten by the Germans. We are too ready to believe that school-work is for school alone, and that the work of students in a laboratory, though perhaps very interesting, has nothing, and cannot possibly have anything, to do with business.

The Germans know better. Not only are their schools fitted with the latest apparatus, and served by teachers of the highest possible education — especially scientific education — but there are in connection with their factories most complete and up-to-date laboratories.

In one chemical works alone there are no fewer than one hundred and fifty trained chemists, busy with experiments, finding out not only new and useful and valuable substances, but easier and cheaper ways of manufacturing the old.

The German manufacturer makes the utmost use of his time; he puts in as long and hard a day's work as any of his men—though his work is mainly supervision; and he makes his sons work as hard as he does.

The splendid schools in which their boys are taught between the ages of twelve and sixteen are another great help to the Germans. The German boy can read and often speak both English and French besides his own tongue; he has a grip of business methods, and of the science needed as a foundation for the industry, into the workshop or office of which he is entering.

And you must not think that this comes to him by the light of Nature. He is no cleverer than an average British boy, and all he does is done by sheer hard work and grit.

Some years ago the words, "Made in Germany," meant that the goods were, as a rule, inferior to those of British manufacture. This is no longer the case. In many industries, in which at one time Britain was first and the rest of the world nowhere, the Germans now hold first place.

This is notably the case in chemicals and in cutlery!

Thirty years ago Germany was an almost entirely agricultural country; but now she has made a mighty forward leap as a manufacturing nation. Her people are crowding from her country districts into the towns, where there is the chance of better pay and greater comfort. The awakening of Germany is a fact with which we shall have to reckon, if we are not to see a falling away of our industries.

A century ago, the United Kingdom made exactly the same kind of forward leap that Germany is making to-day. The other nations were so busy fighting that they had no time to care for manufactures, and Britain had it all her own way. For a long time she far more than held her own; but the immense mineral wealth of the United States, and the attention given to education in Germany, have made the competition of those countries very close and keen.

VI. Sir William Arrol.

IF you were about to build a house for yourself, you would have to employ an architect to design it, or draw the plans, and a builder to carry out the plans and construct the house.

The same course has to be followed when some important structure is to be reared, or some notable feat of engineering to be undertaken; the architect or civil engineer draws the designs from which the contractor is to work.

You will very readily see that each man must be most carefully trained, the one to design the structure, the other to grapple successfully with all the difficult problems that will arise during its construction.

Such a contractor is Sir William Arrol, of Glasgow. He and his firm are willing to undertake any work, however extensive, at any distance whatever from Glasgow. Some of the more notable of the tasks which have been entrusted to him are the Tay Bridge, the Forth Bridge, the Tower Bridge at London, the bridge across the Nile at Cairo, the viaduct across the Wear at Sunderland, and the main viaducts and swing-bridges connected with the Manchester Ship Canal.

It is an inspiring thought that this man, an inventor and designer of wonderful and complicated tools and machines, the builder of some of the most ponderous and important structures the world has ever known, the employer of thousands of skilled mechanics and labourers, began life in the humblest way, raising himself to his present position of honour and usefulness by sheer grit, perseverance, and ability.

Another quality which must be possessed by one who is to undertake the mighty tasks imposed by modern civil engineering, is courage—physical and moral courage. He must have a heart that does not quail before the magnitude of the task, and a faith which not only inspires himself, but communicates itself to those working under his direction.

The power of such a man grows unceasingly; the successful ending of one piece of work shows to him that another and greater is equally possible; so that his life and the influence he wields may be said to be made up of character and experience.

William Arrol was born in the year 1839, in the village of Houston, in Renfrewshire, that shire of Scotland which borders the southern bank of the Clyde from near Glasgow to where the river empties itself into the wide firth. While still a child, he was taken with the rest of the family to live at Johnstone; and it is possible that here, in one of the most important engineering centres of Scotland, his young mind first took the bent which in later years brought him both fame and fortune.

You are aware, of course, that this corner of Scotland is the seat of the cotton industry. In the big cities of Lanarkshire and Renfrewshire, thousands of busy workers spin and card and weave from morning till night, year in and year out. Amongst this toiling multitude was William Arrol's father, who, starting as a spinner, rose gradually from grade to grade, until he became manager of the thread works of Messrs. J. and P. Coats at Paisley.

Long before this, however, William had been contributing his weekly wage to the family purse. It seems strange in these later days to learn that boys of eight and nine should have been expected to undertake steady and sometimes toilsome labour, instead of dividing their time between school and play; but many of the world's greatest men have known very little of formal schooling, or of the happy play of childhood.

William Arrol was only nine years of age when he was sent to one of the big cotton-mills at Johnstone as a piecer; and he was barely more than eleven when he took up a rather better-paid task at the bobbin-turning works of the Paisley firm of which his father afterwards became manager.

The real turning-point in his career, however, came about three years later, when he was bound as an apprentice to Mr. Reid, a blacksmith and engineer. Here he learned the manipulation of materials, and gained that inner knowledge of the strength and nature of iron and steel, which was of such vast assistance in his future work.

His apprenticeship finished, he resolved to gain experience and width of knowledge by working in different centres of industry, observing methods and comparing the value of the various operations connected with the working of metals. After about three years of this wider training, during which he visited many of the more important manufacturing districts of England and Scotland, he returned to the banks of the Clyde, becoming a foreman in the boiler-making and bridge-constructing yard of Messrs. R. Laidlaw and Sons, of Glasgow.

Here he laboured steadily for the next five years, gaining experience in the working of materials and in the management of men, and saving by the most careful economy a sum sufficient to enable him to start on his own account as an employer of labour. So, when still under thirty years of age, this son of the people was able to lay the foundation of the business which has since expanded so wonderfully, opening a small workshop and yard for the manufacture of boilers, girders, and other structures of iron.

The beginning of a new business with a small amount of capital is always an anxious and risky undertaking; but the sterling qualities of William Arrol became known before long to those who had orders to give for work which needed care, forethought, and unremitting attention to detail. The business grew so rapidly that, in little over two years, larger premises had to be obtained. These were situated close to the east end of Glasgow, and were called the Dalmarnock Iron Works.

The excellence of the work here turned out, particularly with regard to the construction of bridges, brought in so many orders that enlargement of the works and the employment of more capital became necessary; and the concern was turned into a limited liability company, Mr. Arrol controlling and directing its operations. Boiler-making was soon discarded, as being less profitable than the other branches of ironwork, and the firm began to be known far and wide as contractors for bridge-building, the construction of iron girder-roofs, and works of a similar nature. It is in connection with bridge-building that William Arrol and his firm have built up their reputation.

Bridges are, as you know, of two kinds, viaducts and aqueducts. Viaducts carry roads and railways over streams or chasms, while aqueducts convey streams or canals across similar depressions.

Again, bridges may be divided into four classes according to the material of which they are built. We may have wooden, stone, brick, and iron or steel bridges; and each class may be further subdivided according to the method of construction employed.

The first bridges were probably formed accidentally by the falling of big trees across narrow streams, affording to our primitive ancestors passage from one side to the other, and thus suggesting wooden bridges across other and wider rivers.

Stone bridges may have been suggested by the wonderful natural arches found spanning deep gorges in wild and mountainous countries; or they may have followed naturally the efforts of early builders to roof over the wide courts of temples and halls.

Bridges do not seem to have been known to the Israelites of old; for we find no mention of them in the books of the Old Testament, though there are frequent allusions to fords. The ancient Babylonians, however, had constructed a bridge across the Euphrates—the earliest of which we have historical record.

The Chinese claim to have been the first builders of arched stone bridges. A very old bridge at Fou-chou-fou is twelve hundred feet in length and thirty-six feet wide. When the bridge was repaired about the middle of last century, the booths or shops with which it was lined were removed.

You are perhaps aware that the solid supports on either bank are known as the abutments of the bridge, and that the intermediate supports are called piers. There is a stone bridge across the estuary of the river at Suen-chou-fou, twice as long as the bridge at Fou-chou-fou, but only about two-thirds as wide, with no fewer than two hundred and fifty-two large stone piers. Spanning the spaces between these piers are huge hewn blocks of stone, forming a solid and level roadway.

One of the chief problems which the early builders had to solve was the vaulting over of wide spaces; and it is most interesting to trace the steps by which this problem was gradually worked out.

The builders of Egypt and Greece usually built up solid walls, and then laid either very long stones or, more usually, timber from side to side. This style of building is known as post and lintel. Some of the later builders of these countries, however, discovered that by allowing each course of stones or bricks to overlap the one below, the sides of the building could be brought gradually nearer and nearer till they met at the top, thus forming a rude arch. In the famous pyramid of Ghizeh, in Egypt, may still be observed arches constructed in this manner.

The Greek bridge-builders seem to have adopted this method in making their bridges. The abutments and piers were built widening course by course, so that at the summit the space to be bridged was quite narrow; then heavy beams were laid from bracket to bracket, forming the foundation of the roadway from bank to bank.

The Romans, however, discovered the principle of the true arch with a central keystone. Their arches were semicircular in shape, massive and enormously strong — though this strength depended perhaps as much upon the excellence of their cement, as upon the skilful laying of the courses.

Many Roman bridges and aqueducts were built of brick; and those who have read Lord

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P.P.

Sir William Arrol.

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Macaulay's poem, "The Lay of Horatius," will remember that the Romans constructed bridges also of timber. All through the provinces of the Roman Empire fine bridges and aqueducts were erected, many of them existing to the present day. The grandest work of all was probably the splendid bridge thrown across the Danube by the Emperor Trajan. This structure had twenty stone piers, each sixty feet wide, and one hundred and fifty feet in height from the bed of the river. Wooden arches, with a span of one hundred and seventy feet, joined pier to pier.

A fine example of the aqueducts built by the Romans can be seen at Nîmes, in France. A series of six arches, forming a bridge four hundred and sixty-five feet in length, supports a second series, stretching over seven hundred and eighty feet from slope to slope of the valley; and over these is a third series of thirty-five arches, extending eight hundred and fifty feet, and supporting the channel in which the stream ran.

England possesses numerous examples of Roman bridge-building. A very fine abutment may be seen at the Chesters, near Hexham, where the Roman wall from the east coast to the west crossed the North Tyne near the Roman camp of Cilurnum.

A very old English bridge is that at Croyland, in Lincolnshire, said to have been built in the middle of the fourteenth century. It is triangular in shape, being supported by three half arches, set at equal distances around a circular base and meeting at the top.

A more ancient bridge was, of course, old London Bridge, designed and begun by a priest named Peter de Colechurch in 1176. It had twenty-two arches; and a street of houses and shops was built upon it. In the year 1756 these houses were taken down, and the three central arches were replaced by one having a span of seventy-two feet.

There are some very strange bridges amongst the Himalayas, in Upper Burmah, and in Eastern Tibet. These are neither more nor less than a strong cable of twisted rattans or canes, slung from a high point on one side of the gorge to a lower point on the side opposite. The traveller seats himself in a loop of leather slung from a sort of wooden shoe supported by the cable, gives himself a vigorous send-off from the bank, and shoots with lightning speed to the lowest point of the cable, the force of his descent carrying him some distance up the sloping rope on the other side. He has then finally to haul himself by main strength to the landing-place.

Some of the mountaineers have, however, thought out a primitive kind of suspension bridge. Two rattan cables are slung side by side, and from these descend at intervals shorter ropes supporting the planks which form the roadway. To cross one of these crazy structures, especially when the whole concern is swaying from side to side in one of the fierce storms which so often sweep through these rocky gorges, needs more than ordinary courage.

We have seen, then, that bridges may be classed as the beam, the arch, and the suspension bridge; though there are many ways in which these three principles are applied. You will see that in the case of a beam, whether it be simply of wood or a wonderfully designed girder of iron or steel, the abutments and piers are subjected only to a vertical strain—the strain caused by the pressure of the load of the bridge itself and of the weight which it may be called upon to bear.

In the case of an arch, however, the abutments have to resist a force of quite a different nature. The arch itself is so constructed that, as long as its ends are kept from spreading out, it can support all the weight likely to be put upon it. If, however, this lateral or sideways thrust is not resisted, the arch will be flattened out. In this form of bridge, the abutments have to be rendered capable of resisting the lateral thrust of the arch, with strong buttresses strutting out behind them. Even so, however, the piers have to support only the downward or vertical pressure, the thrusts of the arches on the two sides balancing each other.

In suspension bridges strong ropes or chains or wires are stretched between towers erected on the opposite brinks of the gulf to be spanned. From these cables, as in the primitive suspension bridges of Central Asia, secondary chains or ropes descend to support the roadway and whatever load it may be called upon to bear. You will notice that the tendency of the weight is to pull together the tops of the towers, and this has to be guarded against by anchoring the ends of the supporting chains into solid abutments behind the towers.

Some famous suspension bridges are the Menai Strait Bridge, the Battersea Bridge, and the Clifton Suspension Bridge over the Avon near Bristol. In all these the suspending chains are formed of links each consisting of a number of flat bars, the links being joined to each other by means of steel pins; and from each link descends a steel rod which forms the support of the roadway platform.

One of our finest stone bridges is the present London Bridge, which replaced the old structure in 1831. It was constructed by Sir John Rennie according to the plans prepared by his father, John Rennie, the famous architect, who died just when the work, the greatest he had ever planned, was about to commence. It is entirely of granite, its five arches carrying it a distance of nine hundred and twenty-eight feet between the massive abutments. The work of building the bridge took seven years to complete.

It was, however, in connection with the building of iron bridges that Sir William Arrol's reputation was established. We like to think that iron bridges were first constructed in this country; but some evidence exists that the Chinese were first in this as in so many other things. However true this may be, it is certain that our engineers did not copy Chinese bridges —their designs were their own.

The first iron bridge to be erected in England was flung across the Severn, and was cast at Coalbrookdale Foundry in 1777. Though the first of its kind in England, it must have been excellently made, for to this day its single arch of one hundred feet span carries traffic over the famous western river.

The second iron bridge was designed by Tom Paine, noteworthy in his day for his free expression of opinion upon religious matters. This bridge crosses the Wear at Sunderland,

and has borne without injury the traffic of more than a century; though, under the supervision of Robert Stephenson, the son of the famous George Stephenson of railway fame, it was widened and repaired in 1858. It has a span of two hundred and fifty-six feet, and the crown of the single arch is ninety-four feet above the surface of the river at low water.

One of the most important pieces of work entrusted to Mr. Arrol in the early days of the Dalmarnock Iron Works was the construction of a bridge across the Clyde at Bothwell for the Caledonian Railway Company. This bridge was built upon the girder principle, the girders stretching from pier to pier across the river, which rolled far below. The piers and abutments having been constructed, Mr. Arrol hit upon a novel method of laying down the platform. Building it span by span upon the bank, he rolled each section out from abutment to pier, and from pier to pier, till the final section reached the abutment on the other side.

Finding that an enormous amount of labour was expended and much valuable time lost, by the cumbrous methods of drilling and riveting the girders and plates, he set about inventing drilling and riveting machines which might travel along the booms of the girders, bore the necessary holes, and rivet the different sections together. This riveting-machine, worked by hydraulic power, has been adopted in the chief bridge-building and ship-building yards of Great Britain and Ireland.

A far more difficult task was now to be entrusted to the firm than any it had yet undertaken. This was the construction of a railway bridge across the Forth above Edinburgh. Such a bridge was necessary to link up the railway systems of north-eastern Scotland with those of the south. A bridge had already been thrown across the Firth of Tay, the design for which had been drawn by Sir Thomas Bouch.

The same designer was asked to draw the plans for a bridge over the Forth, and, had his plans been followed, a beautiful suspension bridge with towers over six hundred feet in height would have spanned the river. Tancred, Arrol & Co., as the firm was then called, secured the contract for the building of the bridge, and a large sum of money had already been spent in the erection of workshops and in preliminary operations, when the work was arrested by a dreadful accident—the destruction of the central portion of the Tay Bridge by the terrible easterly gale of Sunday, December 28, 1879, and the falling into the river of the mail train from Edinburgh to Dundee with seventy-five passengers.

The Tay Viaduct was nearly two miles in

length, crossing the Firth of Tay by eighty-five spans, varying in width from sixty-seven to two hundred and forty-five feet. It contained seven thousand tons of iron, eighty-seven thousand cubic feet of timber, and ten millions of bricks. The cost of building it was three hundred and fifty thousand pounds, and it was at that time the largest iron bridge in the world.

The designer, however, had been directed to prepare plans for a single-line bridge, the cost of building such a bridge being much less than the amount needed for the construction of one to carry a double line of rails. The result of this false economy was that the structure was too narrow for its length and height, and unable to resist the tremendous lateral pressure —pressure upon the side—of an easterly gale.

This frightful accident made people exceedingly nervous about big bridges, and unwilling to construct the bridge over the Forth according to the plans of Sir Thomas Bouch; so, for a time, work was suspended.

Mr. Arrol was asked by the North British Company to suggest a way in which the broken bridge might be repaired and made stronger than before; and he proposed a plan by which the cast-iron columns of the old bridge should be surrounded by columns of steel, the whole being bound securely together by steel braces.

The Parliamentary Committee appointed to inquire into the cause of the disaster, and into the plans for repairing the bridge, would not, however, consent to this mixing of old and new work; so it was at last decided to build another bridge alongside the old one—a bridge with deeper foundations, greater width, and on an altogether different plan designed by Mr. W. H. Barlow.

Mr. Arrol had in the meantime been building a bridge over the South Esk at Montrose, employing a method invented by himself for the sinking of the cylindrical rings which, when filled with concrete and brickwork, would form the foundation of the piers. His method was to carry out these cylinders upon specially designed pontoons, which were fitted with legs so that they might stand upon the bottom of the river, and be raised to the height necessary for the carrying on of the sinking operations.

Having secured the contract for the new Tay Bridge, he decided to employ pontoons of the same kind for sinking the cylinders forming the foundation of its piers; but, since the size of the cylinders was much greater, and since much of the work would have to be carried on at a considerable distance from the shore, the pontoons were made much larger. They were also provided with hydraulic cranes for lowering the cylinders, mechanical diggers for clearing out the sand and mud which would rise within them as they were pressed into position, and machines for mixing the concrete with which they would be filled.

The raising of the girders into position was cleverly managed by floating them out on pontoons to the place where they were needed, and then raising them by hydraulic power to the position they were to occupy, the girders being supported upon temporary columns until the permanent piers were ready.

The bridge was ready for traffic in June, 1887, and was opened on the 20th of that same month, the fiftieth anniversary of the accession of Queen Victoria.

Girders have been mentioned more than once already, and must be mentioned many times more, as they are the weight-bearing members of every great steel and iron structure. It will not, therefore, be out of place to give some short explanation of their nature and the work for which they are designed.

You have all seen the long rails upon which the wheels of engines and wagons run on our railways, and have doubtless noticed that they are made up of two broad flanges with a thinner middle part connecting them. This middle part is known as the "web." Now, a girder is constructed on the same principle—though not always in the same form. There are always the two flanges—called " booms " in very big girders; but the web varies in form and structure. Sometimes it is a simple plate between the flanges, and at right angles to them; sometimes it is split in two, so to speak, making the girder a long rectangular box or tube; and sometimes it is composed of lattice-work, strips of iron or steel being bolted to the flanges or booms and crossing each other diagonally.

Another form of the girder is the "bowstring," a fine example of which may be seen in the railway bridge crossing the Wear at Sunderland. In this form the upper flange is curved, so that the distance between the flanges is much greater at the centre than at the ends. Lattice bracing is usually employed rather than the solid web in girders designed to span a distance of more than a hundred feet.

Each part of the girder has its own special purpose. The upper flange, in an ordinary girder bridge, has to resist the effort of the load placed upon it to bend it by crushing its particles together, while the lower flange has to resist the tendency of the same load to bend it by pulling its particles away from each other. There is also a force tending to tear the flanges apart, and this is resisted by the web connecting them.

You may perhaps have seen some girders with a much smaller flange at the top than below. These are made of cast iron, which is better able to resist a crushing strain than a pulling or tensile strain, so that the upper flange does not need to be so strong, and therefore not so wide, as the lower flange. Steel and wrought iron girders are usually made with equal flanges, their resistance to a crushing and a tensile strain being about the same.

Speaking of girders, the webs of which are divided into two parallel vertical plates between the flanges, so that the whole girder forms a long rectangular box or tube, calls to mind the Britannia Tubular Bridge across the Menai Strait. This whole bridge is really one immense girder, its different sections being bolted strongly together; and the trains run right through the girder itself, from one end to the other.

The Tay Bridge having been satisfactorily commenced, people began once more to talk about the proposed bridge over the Forth; but so great a shock had the fall of the former viaduct caused that the design of Sir Thomas Bouch was abandoned, and a bridge upon the cantilever system decided upon.

A cantilever is really a girder which sticks out beyond the bracket supporting it, and carries a load upon the part which projects. You can see that the weight upon a cantilever will act in the opposite way from that in which a weight acts upon a girder supported at both ends; the upper flange will have to resist the tension, while the lower flange will have to bear the crushing force.

Suppose yourself to have a continuous girder laid over three points of support; and suppose the girder so weak that it bends under the load of its own weight. You will see that where it crosses the supports the upper flange will be in tension, while the lower will be in compression. Where the girder sags, however, between its supports, the upper flange will be in compression and the lower in tension. There must be some point, midway between the highest point and the lowest in each section of the girder, where compression turns into tension or tension into compression. At these points neither upper nor lower flange will have any strain to resist; and even if the girder were divided at these points of contrary flexure, as they are termed, and a hinge substituted for the solid metal, the girder would bear the load just as safely.

This is really the principle upon which cantilever bridges are constructed—a principle said to have been known to the ancient Chinese, but employed by them only in timber bridges.

The Forth Bridge was designed by Sir Benjamin Baker, and was not only the biggest structure of the kind in existence, but was the first bridge to be constructed entirely of steel. The three piers upon which the cantilevers were to depend were built one on each bank and one on the little island of Inchgarvie, which is very luckily placed exactly between the two banks of the river. The two main spans of the bridge—from the Inchgarvie pier to the piers at either side—are seventeen hundred feet in length.

You will gain some notion of the length of these mighty spans, when you are told that the famous Eiffel Tower, in Paris, one thousand feet in height, could lie very comfortably on its side within one of the spans of the Forth Bridge.

The total length of the viaduct is over a mile and a half, and the height of the towers is three hundred and sixty-one feet above high water. Many times during its construction things had to be done which even competent engineers considered impossible; but William Arrol and his staff refused to be terrified by the word impossible; they set to work and designed machines and appliances by which the task was accomplished. As one editor said, commenting in his paper upon the wonderful way in which difficulties were solved: "Arrol and his men have blotted the word 'impossible' out of the English dictionary."

Sixty thousand tons of steel were used in the structure ; and many of the component parts were of so novel a type that special machines had to be invented to manipulate them. Mr. Arrol pursued again his favourite plan of bringing together the parts into the positions they were to occupy, and, while they were held there, of drilling through them the holes for the rivets, which were driven home and clinched by hydraulic power. The travelling drilling-machines were similar in design to those he had employed in building the Bothwell Viaduct.

The sinking of the caissons for the foundations of the piers was one of the most stupendous tasks connected with the building. These vast cylinders of steel were seventy feet in diameter. They were built on shore, launched into the Forth, floated out to the position they were to occupy, and then weighted with concrete till they sank not only to the bottom but far into it. The top of the caisson was air-tight, and compressed air was forced into it to drive out, through the channels provided, the liquid mud and sand dug up by the mighty hydraulic spade directed by the men, who descended into the caisson as into a diving-bell.

These caissons were then filled with concrete, and upon this solid foundation were set the masonry piers needed to support the steel towers.

While this was going on, the approaches to the cantilever portion of the bridge were rapidly being completed. Here massive granite piers, one hundred and fifty feet in height, were built to support the girders carrying the line. A novel plan was adopted in this part of the structure. When the piers had been raised to the height of about ten feet above high-water mark, the girder viaducts were built upon them. They were then raised by hydraulic power as the piers were built higher, so that it looked as if the solid piers were growing slowly with the completed railway line on their heads.

The steel towers having been erected, the cantilevers were built out from either side, tube being riveted to tube and plate to plate. Then the central girders, three hundred and fifty feet in length, and fifty feet between the flanges, were raised and bolted to the ends of the cantilevers, and, except for the minor finishing details, the mighty task was completed.

The bridge was opened on March 4, 1890, by the Prince of Wales, Edward VII.; and at the banquet which followed, the prince announced that the queen had been pleased to confer upon William Arrol the honour of knighthood in recognition of the ability he had shown in achieving so colossal an undertaking.

Before the Forth Bridge had been completed, the firm had undertaken the work of constructing the swing bridges and viaducts by which roads, railways, and canals were to be taken across the Manchester Ship Canal—that waterway which has made Cottonopolis a seaport; and it was also given the contract for the steelwork for the Tower Bridge over the Thames.

The Tower Bridge, though not to be compared with the Forth Bridge for length and weight and difficulty of construction, is yet a very remarkable structure, its lower deck being made up of two bascules, or drawbridges, meeting in the centre. These are raised when a vessel is to be allowed to pass, the foot-passengers ascending by means of granite-cased steel towers to an overhead roadway.

Besides the building of bridges Sir William Arrol and Company have accomplished a vast amount of structural work of other kinds, especially buildings of iron and steel.

The first of these was designed by Sir William himself upon quite novel lines. The great difficulty was the problem of lighting; and this Sir William solved by roofing the entire structure with thick plate glass instead of slates.

So well did this experiment turn out, not only because a greater amount of light was thrown into the interior than by any other system of windows, but also because the cost of upkeep was comparatively small, that the firm followed the same plan in the erection of other workshops, foundries, boiler-shops, and even stables.

Reference must also be made to the Arrol-Foulis stoking apparatus designed for use in gas-works. This machine breaks the coal into pieces of suitable size, lifts it from the coal-stores, charges the retorts with it, and afterwards draw out the coke. The saving effected in labour is tremendous, one gas-works alone saving annually thirty thousand pounds by its use. Hundreds of these machines are now in operation in nearly all parts of the world.

In 1895 Sir William Arrol was elected to the House of Commons as the member for South Ayrshire, retaining the seat until 1906. So many calls were now made upon his time in connection, not only with his political duties, but also with philanthropic and scientific societies, that he gave up to some extent the active management of the business he had built up. He still, however, has a keen interest in the work undertaken by the firm, of which he is the senior partner.

Many men who have made their names famous as contractors and employers of labour have shown a hardness—even harshness—in dealing with their fellow-men; but Sir William Arrol has always been sympathetic and generous towards the smaller firms which have contracted to do work for him, and, through no fault of their own, have failed to fulfil their contract, or have found that their estimate has been too low, so that they would lose instead of gaining money. In such cases he has been known to make good the loss out of his own pocket.

In his fine stone mansion at Seafield, near Ayr, he has a choice collection of works of art, showing that, busy though his life has been, he has found time to cultivate a love for the beautiful.

Men like Sir William Arrol, shrewd, capable, gifted with energy, perseverance and courage, rising to positions of responsibility and usefulness by sheer ability and grit, are an example and encouragement to the whole of mankind.

VII. Wilhelm Konrad Röntgen.

If you place a watch beneath the bell-jar of an air-pump and listen intently, you can hear quite plainly the sound of its ticking; but, if you exhaust the bell-jar of air—so far, that is, as is possible—you may listen as intently as you please without hearing the slightest sound from within the jar.

You have removed from the jar that which conveyed to your ear the sound of the watch's ticking—the air. Sound is produced by the vibration or quivering of the sounding body; and this vibration gives to the air round the body a wave-like motion, resembling that caused on the surface of a pool by the flinging in of a stone. These waves travel rapidly through the air till they reach the ear-drum, and, striking against it, make it vibrate and send to the brain a record of what is going on outside.

But you will notice that when you can hear no sound from the watch you can still see it as distinctly as before; so that the pump has not drawn from the bell-jar the medium through which light travels. Even had you a pump so perfect that you could draw out from the bell-jar nearly every vestige of air, you would still be able to see the watch; and objects on the other side of the bell-jar would be as easily visible as before.

To the medium through which light travels men of science have given the name of "ether." Ether has no weight which can be measured by any apparatus of which we are at present possessed, nor can we say definitely what it is. All that we know has been discovered by observing its power of transmitting light and heat, magnetism and electricity. For, strange as it may seem at first to those who have not thought much about such things, all these four forces—if such they may be termed—and possibly others with which we are as yet unacquainted, make themselves known to us by ether waves of different lengths.

The longer the waves the less rapid is their vibration; the shorter the waves the more frequently do they occur. Waves of the great length of the forty-thousandth of an inch, striking the eye at the rate of five hundred billions per second, cause us to see the colour red; if they were only the eighty-thousandth of an inch long, and coming to us at the rate of one thousand billions per second, we should see violet.

You will perhaps be surprised to hear that if the waves were shorter than the eighty-thousandth of an inch, and striking the retina at the rate of more than one thousand billions per second, we could not see them at all. But it would be foolish for us to say that because we cannot see them they do not exist. As a matter of fact, by means of apparatus much more sensitive to light than is the human eye, we can not only detect their presence but make considerable use of them.

But what about waves longer than the forty-thousandth of an inch, and occurring more slowly than five hundred billions per second? Can we detect them?

Well, very curiously, our bodies can detect none of them until they are very long indeed, and occurring at the slow rate of only one hundred per second. Then we gradually become aware that something is giving off the invisible rays of heat.

You will understand this better if you hold your hand an inch or two from a poker which has been red-hot, but has cooled down to blackness. Rays of heat strike against your hand, warning you not to touch the poker.

But what about the ether waves between those which produce red light and those which produce heat? We cannot say certainly what is the function of all these waves, but scientific men are of the opinion that some are electric or magnetic waves. Of the electric waves we are now making use in wireless telegraphy; the magnetic waves are such as, proceeding from a magnet, influence steel and iron at a distance from their source.

At the other end of the scale we have the waves whose length is less than the eighty-thousandth of an inch, and whose frequency is greater than one thousand billions per second. These waves produce no sensation of light when they fall upon the eye; but they are capable of producing the most remarkable photographs, or "shadowgraphs," as they are called. About·these you will hear later.

Now, what proof have we that light and electricity are closely related — that they are merely effects produced by ether waves of different length?

The first proof is almost conclusive—light and electricity have both been discovered to have a velocity — or speed through space — of one hundred and eighty-five thousand miles per second.

The second proof is quite as satisfactory, though it takes rather more explanation. You know that polished surfaces reflect light, throwing it in any desired direction; that the rays of light can be refracted or bent, by passing them through water or thick glass or other transparent substances; and that, with a convex lens or burning glass, a bundle of rays may be brought to a point or focus. Now, by the use of suitable apparatus, electric rays may be made to go through the same changes: they can be reflected, refracted, and brought to a point or focus.

You have already seen that, though all the air from a bell-jar may be drawn off, the ether remains; but it may cause surprise to learn that the ether can pass easily in and out of the bell-jar through the glass itself, or through the brass plate upon which the bell-jar stands. The fact is, all the atoms or molecules of which everything is composed are surrounded by ether—swing in it, so to speak. When the substance is heated, the atoms or molecules swing farther and take up more room, thus causing the substance to expand; but, no matter how far they swing, as long as the substance remains solid there is not sufficient room between the particles to allow air to enter.

You can now understand how light is able to pass through glass and other transparent substances. The ether between the particles passes on the light waves to the other side.

The difficulty at once crops up, of course, why any substance should be able to prevent the light waves from passing through it, seeing that its atoms or molecules are in the same way surrounded with ether. This is a most interesting problem which has not yet been fully solved. Something of the reason may perhaps be arrived at, by considering the manner in which other ether rays are affected by various substances.

If you hold a sheet of tin between yourself and a hot fire, you will prevent any light coming through to your eyes; but the head of a match placed upon your side of the tin will soon flare up, showing that though the light rays were shut out the heat rays have found a passage through.

Instead of a tin sheet, place between yourself and the fire a thin glass tank of alum and water. You will see the fire perfectly, and so be certain that the light rays are coming through, but your match head may stay as long as you please without catching fire; for the alum and water refuse to allow any heat rays to pass.

You have probably seen the porcelain insulators on telegraph poles, placed there to prevent the electric current from flowing from the wire into the pole and so to the earth and back to its starting-point. Porcelain then, though its molecules are surrounded with ether, will not allow electric vibrations to pass through it. Glass and several other substances have the same power of shutting out electricity; so that, though glass may be transparent to light, it is not transparent to electricity.

These strange differences in the transparency of various substances to the different kinds of ether rays have been explained in this way. The spaces between the particles of the body are of such a nature that waves only of a certain length and frequency can get through them. Thus, light waves can pass through glass, but not through tin; heat waves can pass through tin, but not through alum and water; electric waves can pass through tin or wood, but not through glass or porcelain.

Recently, however, it has been found that certain rays can pass through any solid substance — though they penetrate some substances much more readily than they do others. These are the rays at the top of the scale — those shorter than the eighty-thousandth of an inch, and occurring at the rate of more than one thousand billions per second. Whether these waves should be called rays of light, or rays of electricity, or of something else, has not yet been decided. Since they are invisible, it does not seem proper to call them "light" —and yet in many ways they exactly act as rays of light might be expected to act.

These wonderful rays were discovered by Professor Wilhelm Konrad Röntgen, and named by him "X-rays" because he was unable to decide their nature.

Before you hear more about the discovery of these rays, and of the remarkable properties which have made them such a blessing to mankind, it will perhaps be well to know something of the life-story of their discoverer. If we follow his career step by step, we may be able to decide what it was in his character or in his training which fitted him to become one of the really great among mankind, one with an imperishable name, one to whom is due the gratitude of the human race.

Wilhelm Konrad Röntgen was born on the 23rd of March, 1846, at Lennep, in Rhenish Prussia, and thus belongs to that nation so justly famous for the untiring patience, devotion to duty, and culture of its people. In the article upon the life-work of Sir William Perkin you have already read about the thoroughness of German educational methods, and you will understand something of the thirst for knowledge which distinguishes the German student.

When his primary education was sufficiently advanced, young Röntgen was sent to the University of Utrecht, in Holland. A better choice could scarcely have been made. Utrecht has long stood very high as a centre of education; its university equips for their future duties professors of mathematics and languages, doctors, priests and lawyers; while its fine observatory and its botanical garden show that physical science is by no means neglected.

The beautiful aspect of the city would appeal powerfully to the fresh, receptive mind of the young German. Entering it for the first time from Amsterdam, as he would probably do, he would be charmed with the beauty of the long avenue by which it is approached, and by the air of antiquity which seems peculiarly to belong to it, partly, perhaps, because of the Gothic architecture of its houses, the height of its cathedral tower, its ring of forts, and its broad ramparts —now converted into exceedingly pleasant public walks.

The cathedral tower, by the way, is separated by a wide street from the choir and transept; but across that space at one time stretched the noble nave or body of the cathedral, which was hurled down by a furious hurricane in the year 1674, and never rebuilt.

Lennep, Röntgen's birthplace, is only a little over twenty miles from the Rhine, and Utrecht, where he was now sent, is divided into two parts by the same river. Besides the river, two canals run through the city, people crossing from one side to the other by means of no fewer than thirty-six drawbridges.

A walk much beloved by the students is the Maliebam, more than a mile in length, and shaded by eight rows of lime-trees. From the top of the cathedral tower, almost four hundred feet in height, when the weather is clear, very nearly the whole of the Netherlands may be seen. Utrecht itself, unlike many other Dutch towns, stands fairly high, the banks upon which the main streets are built being considerably above the level of the river; so that the air is purer and the site drier than at Amsterdam or Rotterdam.

Few things appeal more to a young and impressionable nature than the thoughts that great events have happened, that famous men have lived and worked, that history has been made in the places where now its own lot is cast. To Wilhelm Röntgen, fresh from his uneventful life in the little Prussian town where he had been born, the associations of Utrecht must have acted as a powerful mental stimulus.

Here the Romans crossed the Rhine after subduing the Belgæ—the modern name of the city is an attempt on the part of Frisian tongues to pronounce the old Roman name—and here the noted Englishman, St. Willebrod, was consecrated bishop after baptizing some thousands of the Frisians, whose language was so wondrously like his own.

Utrecht, though the worship in its mutilated cathedral is now rather that of the Presbyterian Church than that of the Church of Rome, was the birthplace of Pope Adrian VI. In the year 1579, the Act of Confederation which united the seven provinces of the Netherlands against the power of Spain, was signed in the hall of Utrecht University. Many of you will no doubt remember that the War of the Spanish Succession was ended by the Treaty of Utrecht, signed in the British Minister's house. The city has also been, though for only a short time, the seat of the government of the country; for here, while king of Holland, Louis Bonaparte, the brother of Napoleon, held his court.

It must not be supposed, however, that Utrecht is a decaying city, with its glories all in the past. On the contrary, it is a thriving industrial and commercial centre. It has manufactures of woollen cloths, carpets, velvets, needles, cigars and tobacco, salt, baskets, rope, furniture, and articles of tin, copper and silver, besides chemicals, bricks, machinery and beer. It contains saw-mills, iron-foundries and printing-works, and is the centre of the cattle and grain trade of the district.

In the university, Röntgen would be one of over eight hundred students being trained for service in many walks of life.

But the education obtainable at Utrecht, thorough and extensive though it was, does not appear to have been considered all that Röntgen needed; and he was sent to Zürich, "the Athens of Switzerland," as it has been called, because of its people's culture and zeal in educational matters.

Here again he was on historic ground. The museum contains the crossbow said to have been used by William Tell in shooting at the apple on his son's head; and in the library are three Latin letters written by Lady Jane Grey. Coverdale's Bible, from which are taken the Psalms included in the Prayer-Book of the English Church, is believed to have been printed at Zürich in 1535.

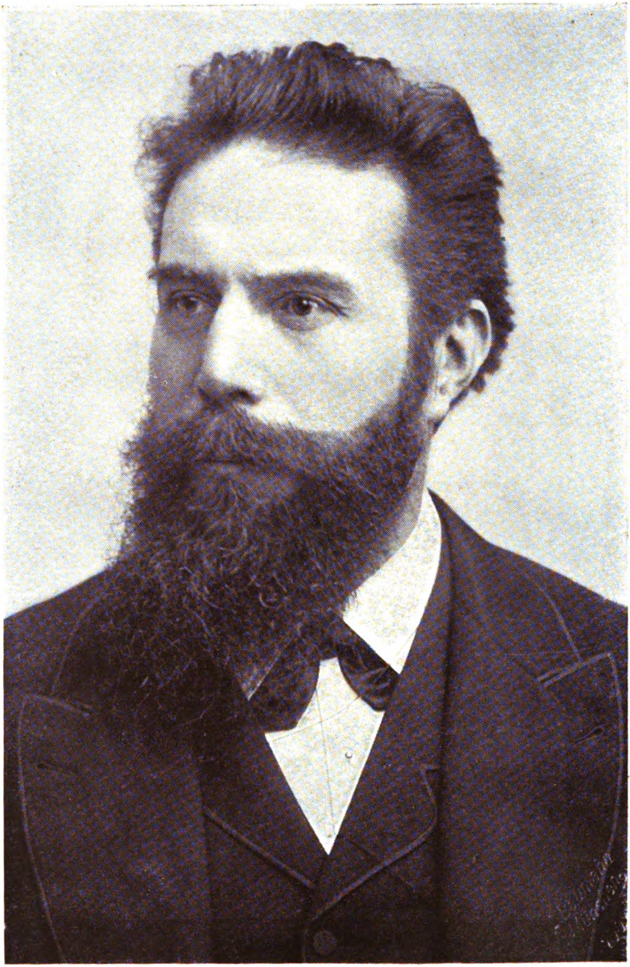
The city is charmingly situated at the north-west end of the Lake of Zürich, the River Limmat running through it from the lake, and being crossed by five fine bridges. In its grand old cathedral the reformer Zwingli preached early in the sixteenth century.

Like Utrecht, Zürich is a busy manufacturing city, sending away large quantities of silk, cotton, and machinery. It is not only the centre of the Swiss silk industry, but the largest and most important town in Switzerland.

Here Röntgen studied till 1869, taking in that year the degree of Doctor of Science. During his educational course he had been keenly interested in the problems of physics and electricity, and he has done a vast amount of valuable research work in those sciences—though to the world in general he is known because of his discovery of the X-rays.

The people of Zürich doubtless thought of him simply as one of the many students seeking their ancient city on account of its educational advantages. They could not be expected to realise that the tall, thin man, with the bushy beard and pale, thoughtful face, who walked often at a rapid pace through their busy streets, was one of whom in the years to come they would be vastly proud, as partly the product of their own university.

Only when he was speaking earnestly upon some question which interested him could it be seen that he was above the ordinary run of men. His deep, musical voice and expressive, compelling eyes enchained his hearers ; his thoughts crowded upon each other till his rapid speech seemed too slow to give them



P.P Wilhelm Konrad Röntgen.

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utterance. During these days he fell into a habit which has since been a source of innocent amusement to his students—the habit, when excited, of unconsciously running his fingers through his hair till it stands up like a mop all over his head.

The record of Röntgen's life after leaving Zürich is one of hard and unceasing labour as a teacher and experimentalist. His work as assistant to the professor of physics at Würzburg and Strasburg led to his appointment as Professor of Mathematics and Physics at the Agricultural Academy of Hohenheim in 1875. That his work at Strasburg had been of no common order was proved by his appointment in 1876 to a professorship at the university of that city.

It is remarkable that two such men as Pasteur and Röntgen should each have been a professor at Strasburg — Pasteur at the French university academy, and Röntgen, when the city had passed into the hands of the Germans, and the ancient university had been reopened after being suppressed for over eighty years.

The history of the ancient "town on the road," as its name might be translated, has been a most interesting one. Built in the first place by the Romans, it was destroyed by the German tribes who invaded Gaul to attack the weakening power of the world's conquerors. Years afterwards it was rebuilt, gradually increasing in importance till in the middle of the thirteenth century it became a member of a league of cities on the Rhine. This league maintained a large force of archers, who in one hundred boats patrolled the Rhine, guarding its commerce from robber nobles and greedy prince-bishops.

For nearly three centuries the city maintained its independence; but in the year 1681 it was surprised by Louis XIV.'s troops, and became a French town and fortress.

Although its importance and prosperity increased under French rule, its people and its appearance long remained German; and the German people may be excused for regarding it as a valuable national property wrongfully snatched from them.

Strasburg Cathedral is exceedingly beautiful, famous alike for the perfection of its architecture, the height of its splendid spire—one of the highest in the world—and its wonderful astronomical clock, which shows the day and the month, the positions of the sun and moon and planets, besides the hour and the minute. This clock was constructed in 1571, and continued going for two hundred years before getting out of order. Then it stood silent for fifty years, because no one was able to repair it, till at last, a watchmaker belonging to the city managed to set it once again in working order.

A few years before Röntgen began his duties as a professor in its reopened university, Strasburg had gone through the experience of a siege. For weeks its walls and houses had been bombarded by German guns—though the gunners were exceedingly careful not to damage the cathedral—and it had been compelled to surrender after more than five hundred houses had been destroyed and over eight thousand people rendered homeless.

Strasburg has in every way prospered since coming under German rule. It has for centuries been an important manufacturing town —a mere list of all its industries would occupy a dozen lines or more—but its trade has vastly increased during the last forty years. Once more Röntgen had become a citizen of an historic and important city.

For about three years Röntgen lectured and studied at Strasburg, and was then appointed Professor of Physics and Director of the Physical Institute in Giessen, a city of Hesse-Darmstadt, on a tributary of the Rhine. It is interesting, though by no means significant, to note that Röntgen has lived always in towns and cities within the Rhine basin—even Zürich stands at the outlet of a lake the waters of which are drained into the Rhine.

At Giessen, Röntgen had once again the inspiration of knowing that he was labouring where notable work had been done; for it was at Giessen that the famous chemist Liebig founded his School of Chemistry, which attracted students from all over Europe, and where also he began those discoveries which have made his name renowned.

Dr. Röntgen was now well known as an earnest seeker after new truths, and as an accomplished lecturer; but his supreme discovery, which has placed him in the same rank as Simpson, Pasteur, and Lister, was not made till 1895, ten years after his appointment to be Professor of Physics at Würzburg, and when he was fifty years of age. Nearly forty years had been spent in arduous study, before the reward came to him of finding out something which has not only rendered him famous, but has benefited enormously his fellow-creatures.

To understand exactly what it was that Röntgen discovered, we must think again of the ether waves, and especially of those at the upper end of the scale—those shorter than the eighty-thousandth of an inch, and therefore invisible.

The story reads almost like a fairy-tale; and yet it shows how wonderfully the discoveries of one man are built upon the labour of others who have gone before him.

Many of you doubtless have taken part in little experiments with a small electric battery; and know that if wires ending in small metal knobs are attached to the positive and negative poles of a battery, and the knobs brought within a short distance of each other, electric sparks pass between them, showing that the electric current is jumping across the gap in order to complete its circuit.

If the knobs or terminals are inserted one into each end of a vessel from which the air can be pumped out, not only can sparks be obtained by the use of a current of much less strength, but a peculiar change takes place in the sparks themselves — they are, in fact, no longer sparks.

When the pressure inside the vessel has been reduced, till it is only from one five-hundredth to one fifteen-hundredth of that of the air outside, a kind of thin veil of light—if such a term can be employed — is seen round the negative knob or terminal—the "cathode," as it is called. Then comes a dark space, then a slight glow, then another dark space, and, lastly, a bright glow reaching to the positive knob or terminal—the "anode," to give it its proper name.

When, however, the pressure is reduced, until hardly any air is left in the vessel, a still more beautiful effect is produced. All the glows die out except that round the cathode—the negative knob. This changes into a beam of blue light going straight out from the knob—a beam of light having the peculiar property of making the glass of the vessel, upon which it strikes, glow with phosphorescent light—like that produced by rubbing wet matches in the dark, or that seen upon fish which are not quite fresh. Whatever the beam may fall upon, whether glass or anything else, soon becomes intensely hot.

Many men of science have experimented with these rays, gradually finding out more about them, and making more perfect apparatus for their production.

Geissler—the famous German who proved that water is heaviest when its temperature is nearly four Centigrade degrees above freezing-point—invented a glass tube, narrow in the middle, and having a sort of tube at the side by which it could be connected with an air-pump. Into the ends of this tube he sealed the terminals of an electric coil, and thus showed the beautiful effects produced when the pressure of air was not too much reduced.

Hertz, after whom the electric waves through the ether have been named, went a step further, and, by reducing the pressure still more, produced the blue beam or "cathode" rays.

Sir William Crookes, experimenting upon the same lines, with a splendid air-pump invented by Sprengel—the German chemist who worked in Oxford and London, and who found out many things about high explosives such as lyddite and melinite—obtained even better results than Hertz, and invented a "vacuum tube" much more perfect than Geissler's. This "Crookes' tube" is four or five inches in diameter in the middle, but tapers away towards each end. Through one end passes a platinum wire, ending in a plate of platinum about the size of a halfpenny, but shaped like a saucer.

The wire must be of platinum, because the glass has to be melted around it to make the tube air-tight, and no metal but platinum cools at exactly the same rate as glass; so that if any other were used, the glass would crack in cooling, and the tube be rendered useless.

The effect of the saucer-like shape of the platinum plate is like that of a burning-glass upon the sun's rays — it brings the cathode rays to a point, or focus. Another platinum plate is fixed here—at the focus—at such an angle that it throws the rays through the side of the tube. The platinum saucer is thus the negative terminal of the electric coil. The positive terminal, or anode, is taken through the glass in the same way, but at one side. It is bound to be there, or there could be no rays; but it is the rays from the cathode, or negative terminal, which the experimenters have proved to possess such marvellous properties.

Hertz had an assistant called Lenard, a young Hungarian, who was keenly interested in these cathode rays. By way of experiment he put a plate of aluminium into the side of a Crookes' tube just where the rays came through, and found to his delight that the rays penetrated the aluminium. He ascertained that they would affect a sensitised plate—such as is used in photography—even though it were enclosed in a metal box. He also learned that they could be attracted by a magnet and turned out of their course. These "Lenard rays," as they are called, do not continue in a beam after passing through the aluminium "window," but separate widely and are soon lost to sight.

This discovery of Lenard's was made in 1894—just a little over a year before Röntgen's crowning discovery of the X-rays. So far, although everything found out by these patient investigators was exceedingly interesting to other scientific men, the results seemed of little use to people in general. It is possible that many persons, reading about their experiments, thought they had spent a great deal of time and money to very little purpose. But Röntgen's discovery, which was hailed with delight because of its immense importance to mankind, was made possible only by the steady, earnest work of those who had gone before him.

In the year 1895, in his house at Würzburg in Bavaria—another wonderfully interesting old city, with one of the finest palaces in the world, and situated on the Main, another feeder of the Rhine—Röntgen ascertained that, issuing from the Crookes' tube with the cathode rays, were other invisible rays possessing the astonishing power of penetrating almost every kind of solid body, even after they had passed through the glass of the tube.

Professor Röntgen, who was keenly interested in the various experiments made with Crookes' tubes, set to work patiently to inquire into the nature of the rays about which there had been so much discussion. After examining the cathode rays and the Lenard rays, he carefully arranged an experiment to ascertain if it was not possible to shut in the cathode rays altogether. After connecting his Crookes' tube with the electric coil, he covered it carefully with a thick black cardboard shield.

He could now perceive no light at all coming from it, but, in order to be quite certain, he covered the window of his laboratory, and every chink where light might penetrate from outside. To his eyes everything was now perfectly dark, except that a phosphorescent glow appeared on a table just below the Crookes' tube.

Going eagerly forward, he saw that it was a bit of sensitised paper which was glowing—a piece of paper smeared over with a chemical preparation such as is used in photography, because it is most sensitive to light. He removed the paper, and the glow ceased; he tried most carefully to detect any chink in his shield through which the cathode rays from the tube might have escaped—but there was no such chink, nor could he see any rays at all escaping. When he replaced the sensitised paper, however, the glow appeared at once.

The professor now tried covering the Crookes' tube with a thicker covering—but the sensitised paper still glowed. Hardly able to believe the evidence of his own senses, he continued experimenting. Taking up a thick book, he put it between the tube and the paper, and was almost startled to find that it made very little difference

—the paper still glowed; so that the rays, whatever they might be, passed through the solid book without trouble.

Cards, wood, and metal were all in turn tried; and it became evident that, though some of these bodies hindered to some extent the passage of the rays, not one could shut them out altogether. At last the professor placed his own hand between the tube and a photographic plate, and found that he had a strange and wonderful photograph—the strangest photograph that had ever been taken. For, since the rays had gone through the flesh of his hand much more easily than through the bones, the photograph showed the skeleton of his hand in dark shadow, with the much lighter shadow of the flesh showing round the bones.

Dr. Röntgen realised that he had made a most wonderful discovery—one which would enable surgeons to examine a man's skeleton while he was still alive, and to detect the presence of a bullet or any hard substance embedded in his flesh without the horrible probing that had been necessary up till 1895.

He experimented for some time to make sure that the rays would always act; and he racked his brain for some explanation of them without arriving at any satisfactory conclusion. At last, in despair, he called them "X-rays," the letter "x" being used, as you know, in algebra, for the unknown quantity.

But, if the rest of the world, to whom he revealed his discovery about a month later, could explain the nature of the rays no better than he could, they saw the immense importance of such a splendid help to the surgeon; and Röntgen leapt into fame. All the scientific men of the civilised world hastened to experiment with the rays, and in almost every hospital an X-rays apparatus was soon in constant use. It was very simple, and easily fitted up—all that was needed being a battery, a coil to strengthen the current, and a Crookes' tube.

You can judge of the usefulness of an apparatus whereby the progress of a broken limb can be ascertained without removing splints or bandages; by which the size, shape, and position not only of the bones, but of heart, lungs and liver, can be judged without any distress to the patient; by which a surgeon can locate a needle or bullet in the flesh as easily and accurately as if the man's body were made of glass.

Edison, the American inventor, has invented a piece of apparatus called a fluoroscope by which the rays have been rendered very easy of application. It is a sort of box, one side of which is made of thin cardboard covered with a chemical mixture like that upon Röntgen's sensitised paper; and the opposite side fits closely upon the surgeon's eyes. The part to be examined is brought between this fluoroscope and the Crookes' tube, and the surgeon is able to detect at once anything wrong.

Some curious stories are told of discoveries made by means of the X-rays. One of the funniest is about a woman who came to a doctor in very great trouble, to tell him she feared she must have some of her toes taken off altogether because they gave her such terrible pain. She said she could hardly bear to walk, and sometimes the mere putting on of her boots was absolute agony.

After examining her feet the doctor was pretty sure he knew the source of all the trouble—she had for years worn boots far too small for her, and her toes and the bones of her feet were bent and twisted—but to get her to acknowledge such a thing and to wear boots of a proper size would have been a very difficult matter had it not been for the X-rays.

The doctor took a shadowgraph, or "skiagraph," as it is called, and showed it to the horrified woman, who promised at once to get broad-soled, comfortably large foot-wear.

A peculiar use to which the rays have been put is that of telling sham diamonds from real ones. When a genuine diamond is placed between the Crookes' tube and the photographic plate, hardly any shadow is left; but the false stone gives a very distinct photograph, no matter what may be the composition of the paste of which it has been formed.

You would hardly think that these wonderful rays could distinguish unerringly a false mummy from a genuine Egyptian relic; but such is the case. An American lady, who had visited Egypt, had bought at great cost, and brought back with her, what she believed to be the hand of a mummy, taken from its ancient resting-place in the land of the Pharaohs. She became alarmed, however, when one of her friends, who knew a great deal about such matters, assured her that she had been deceived, and that the supposed hand was really only a lump of pitch and plaster wrapped in some old mummy-cloth.

In order to settle the question once and for all, she had an X-ray photograph taken of the relic, and was able to triumph over her learned friend; for there, plainly to be seen, were all the bones of the departed Egyptian's hand.

One of the first Englishmen to benefit by the doctor's discovery was a young man about nineteen years of age, who would most certainly have lost a finger but for the rays.

He had been struck by a ball upon the end of his little finger, and the blow had so damaged the last joint that it remained half-bent. When he attempted to straighten it or to close his hand he felt very great pain.

The surgeons who examined the finger thought the only thing to be done was to cut off the damaged portion, so that he might regain the use of his hand; but to this he was very naturally unwilling to consent. Some one suggested that he should have the finger examined by means of the newly-discovered X-rays; and then the cause of the trouble was quite clear. A little bridge of bone had grown, joining the last two joints of the finger together. A very simple operation by which this bone was snapped gave him once more complete control of his finger.

Many more instances might be given of the usefulness of these wonderful rays, particularly to surgeons and physicians; but enough has been said to show how indebted is mankind to this patient investigator, and how thoroughly he deserves all the honours that have been showered upon him.

Röntgen received many decorations and congratulatory speeches. Among the decorations were one from the Kaiser, and the Rumford medal of the Royal Society of England.

No army now goes into active service without a complete X-rays apparatus; and in recent wars many lives have been saved, and much pain to wounded men has been avoided, by its means.

Many clever doctors believe that the X-rays may also be used in the destruction of the germs of such terrible diseases as cancer, consumption, diphtheria, and typhoid fever.

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